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THESIS

A PRELIMINARY STUDY: USMC TACTICAL COMMUNICATIONS TECHNICAL CONTROL NEEDS FOR THE LANDING FORCE INTEGRATED COMMUNICATIONS SYSTEM

by

Donald E. Creighton

September 1985

Thesis Advisor: Jack W. La Patra

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This study uses a systems analysis approach to determine the communications technical control needs of the Fleet Marine Force as the transition from analog to all digital systems occurs. Introductory material is presented on the Landing Force Integrated Communications System (LFICS) and associated methods of communications system control. The decision problem is stated as a needed choice between alternatives in both near term (1987-1990) and

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20. long term (1991+) eras of service. Examined are the technical control functional requirements for both the transitional near term and the eventual long term digital systems. The study raises issues on the automation of technical control in the development of a systems engineering functional description of an "ideal" facility. Consideration is given to the many other service and industrial solutions in the formulation of ten alternative approaches to the total solution of communications technical control in the near and long term. A qualitative, ordinal valued, multicriteria decision theory model is applied to the selection between these alternatives as opposed to a more quantitative cost and operational effectiveness analysis (COEA) study approach. The decision model is fully developed for this application and for general future use by the interested reader. Conclusions and recommendations are made based on analysis of the modeling results. Appendices provide necessary supporting detail and include issues and topics for future study.

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A Preliminary Study:
USMC Tactical Communications Technical Control Needs for the Landing Force Integrated Communications System

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This study uses a systems analysis approach to determine the communications technical control needs of the Fleet Marine Force as the transition from analog to all digital systems occurs. Introductory material is presented on the Landing Force Integrated Communications System (LFICS) and associated methods of communications system control. The decision problem is stated as a needed choice between alternatives in both near term (1987-1990) and long term (1991+) eras of service. Examined are the technical control functional requirements for both the transitional near term and the eventual long term digital systems. The study raises issues on the automation of technical control in the development of a systems engineering functional description of an "ideal" facility. Consideration is given to the many other service and industrial solutions in the formulation of twelve alternative approaches to the total solution of communications technical control in the near and long term. A qualitative, ordinal valued, multicriteria decision theory model is applied to the selection between these alternatives as opposed to a more quantitative cost and operational effectiveness analysis (COEA) study approach. The decision model is fully developed for this application and for general future use by the interested reader. Conclusions and recommendations are made based on analysis of the modeling results. Appendices provide necessary supporting detail and include issues and topics for future study.

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LIST OF ABBREVIATIONS, ACRONYMS AND DEFINITIONS

2-W	2-wire circuit
26-Pair	26 pair assault cable CX-4566
4-W	4-wire circuit
A/D	Analog-to-Digital
AC	Alternating Current
AIS	Automated Information System
AMDF	Analog Main Distribution Frame
bps	bits per second
BER	Bit Error Rate
BIT	Built-In-Test
BITE	Built-In-Test-Equipment
C-E	Communications-Electronics
CM	Configuration Management
COAX	COaxial CAble CX-11230
COEA	Cost and Operational Effectiveness Analysis
COMSEC	COMMunications SECurity
Cond Diphase	Conditioned Diphase
CESE	Communications-Electronics System Element
CNCE-M	Communications Nodal Control Element (Management)
CNCE-T	Communications Nodal Control Element (Technical)
COMMCCN	COMMunications CONtrol
CPE	Collective Protection Equipment (nuclear, biological, chemical)
CRT	Cathode Ray Tube
CSCE	Communications System Control Element
CSPE	Communications System Planning Element
CVSD	Continuously Variable Slope Delta
DC	Direct Current
DCA	Defense Communications Agency
DCE	Data Communications Equipment
DCS	Defense Communications System
DGM	Digital Group Multiplexor
DMDF	Digital Main Distribution Frame

DT	Developmental Testing
DTE	Data Terminal Equipment
DTG	Digital Trunk Group
ECP	Engineering Change Proposal
ECU	Environmental Control Unit (air conditioner/ heater)
EW	Electronic Warface
FDUX	Full DUpleX
FM	Field Manual (US Army)
FMF	Fleet Marine Force
FMFM	Fleet Marine Force Manual (USMC)
FOM	Figure of Merit
FSSG	Force Service Support Group
Gbps	Giga bits per second
GHz	Giga hertz
HDUX	Half DUpleX
HMDF	Hybrid analog/digital Main Distribution Frame
ILS	Integrated Logistics Support
JINTACCS	Joint Interoperability of Tactical Command and Control Systems
JTAO	Joint Tactical Air Operations
JTC3A	Joint Tactical Command, Control and Communications Agency (formerly TRI-TAC)
Kbps	Kilo bits per second
kHz	kilo hertz
KW	Kilo Watt
LCC	Life Cycle Cost
LCE	Line Conditoning Equipment
Level <0>	mission essential capability only
Level <1>	mission essential capability plus minimum manual capability enhancement
Level <2>	mission essential capability plus nominal manual, semi-automatic enhancement
Level <3>	mission essential capability plus fully automated maximum capability enhancement
LFICS	Landing Force Integrated Communication System
LPC	Linear Predictive Coding
MAB	Marine Amphibious Brigade

MAF	Marine Amphibious Force
MARDIV	Marine Division
MAW	Marine Aircraft Wing
Mbps	Mega bits per second
MDF	Main Distribution Frame
MEP	Mobile Electrical Power
MHz	Mega hertz
MIFASS	Marine Integrated Fire and Air Support System
MOS	Military Occupational Specialty
MPLX	Multiplex(or/ed)
MOE	Measure of Effectiveness
MSARC	Marine (Corps) System Acquisition Review Council
NRZ	Non-Return to Zero
OSC	Operational System Control
OSCC	Operational System Control Center
OT	Operational Test
PCM	Pulse Code Modulation
PTF	Patch and Test Facility
SPE	Systems Planning and Engineering
SW	SWitching equipment
SYSCON	SYStem CONtrol
TADIL	TActical Data Information Link
TAOC	Tactical Air Operations Center
TCCF	Tactical Communications Control Facility
TCF	Technical Control Facility
TCO	Tactical Combat Operations
TDM	Time Division Multiplexing
TECHCON	TECHnical CONtrol
TECHCONFAC	TECHnical CONtrol FACility
TMDE	Test, Measurement and Diagnostic Equipment
TRI-TAC	TRI-service TACtical communications agency (obsolete, now JTC3A)
TSO	Telecommunications Service Order
TSU	Test Select Unit
TTY	Teletype

ULCS	Unit Level Circuit Switch
VF	Voice Frequency
WD-1/TT	twisted pair 2-W HDUX "slash wire"
WF-16/TT	twin twisted pair 4-W FDUX

I. INTRODUCTION

A. PURPOSE

This study is planned to provide the basis for more specific follow-on studies in the area of USMC digital (and residual analog) technical control needs in the near term (1987-1990) and the long term (1991+). It will provide a framework for decision among alternative choices to initiate action to modify or replace the existing communications technical control center, AN/TSQ-84, in order to satisfy the functional requirements for communications technical control in the Fleet Marine Force (FMF). Additionally, it will provide an assessment of all technical control functional requirements during this analog to digital transitional period.

B. SUMMARY OF REQUESTED STUDY

Technical control of communications systems is presently implemented at Marine Amphibious Force (MAF), Marine Division (MARDIV), Marine Aircraft Wing (MAW) and Force Service Support Group (FSSG) command posts by the employment of the Communications Technical Control Center, AN/TSQ-84. This facility provides for the Technical Control (TECHCON) functional requirements described in FMFM 10-1 [Ref. 1: pp. 3-16, 3-17] and has proved adequate for the analog architecture of existing Fleet Marine Force (FMF) communication systems. The result is a single focus for the execution of Systems Control (SYSCON) planning, installation, operation and maintenance technical directives in the employment of these FMF systems. With the Department of Defense (DOD) commitment to transition to an all digital communications environment in the FMF, it is essential that the TECHCON be capable of meeting the needs of the emerging digital technology and systems architecture.

C. STUDY OBJECTIVES

This study is to determine the digital technical control requirements, and discuss the modification or replacement of the AN/TSQ-84 to provide the necessary facilities in a digital (and residual analog) communications environment. This will provide an essential element in assessing the impact of digital systems and digital data communications on the Landing Force Integrated Communication Systems (LFICS) architecture [Ref. 2: Chapter 5].

There are three explicit basic tasks:

1. Determine which of the FMFM 10-1 TECHCON functions apply in a digital environment.
2. Identify implementation methods for these digital TECHCON functions.
3. Determine to what extent the AN/TSQ-84 can accomodate the digital functions; and, if deficient in digital TECHCON functioning, determine modifications to the AN/TSQ-84 which would satisfy these requirements or identify alternative solutions.

D. STUDY PLAN OF ATTACK

A survey of all development activities in the USMC and other services will be conducted to identify unilateral and joint service "work-in-progress" and alternative solutions related to digital technical control. Both commercial and military literature will be reviewed for technological impact. The ultimate goals of this process are to identify and exploit mutually satisfactory applications of digital technology, research, and development, and insure a high degree of compatability between fielded technical control facilities. The documents which will determine the viable USMC alternatives and solution will be the FMFM 10-1 and the USMC Command and Control Master Plan [Refs. 1,2] in agreement with emerging digital network management technology, and interoperability constraints identified relative to the other military services and industry.

The presentation includes necessary introductory material, such as: a description of the USMC landing force integrated communications system (LFICS), and a brief discussion of network control and management. Following this introductory material, the study will focus on a discussion and presentation of the need, mission, and functions of digital technical control in the LFICS; a presentation of several alternative solutions; an application of multicriteria decision theory in the selection of a "best/better" alternative; and conclusions and recommendations. Also included, as Appendix G, are topics for future study.

The reader is encouraged to refer to the sectioned bibliography. While many works are included which are not cited by reference, the list provides broadly categorized sources which range from introductory topics to material of great depth and complexity. It offers an excellent starting point for future research into the issues raised in this study.

E. STATEMENT OF THE NEED

The basic assumption during the following discussion is that the existing technical control facility, AN/TSQ-84, will either prove to be totally inadequate for the mission or it will be clearly inferior to other existing, developing or new start facilities. Under these conditions, the discussion begins with a summary statement of the need(s):

Need 1: Near Term (1987-1990)

Determine what systems and/or equipments are required to meet the needs of near term hybrid analog/digital technical control in the LFICS.

Need 2: Long Term (1991+)

Determine what systems and/or equipments are required to meet the needs of long term all digital technical control in the LFICS.

II. LANDING FORCE NODAL COMMUNICATIONS

A. MILITARY COMMUNICATIONS SYSTEMS - GENERAL

It must be remembered throughout the following discussion that, although military systems may appear similar to commercial systems, there is a basic assumption which must not be overlooked. As stated by Torrieri:

> "In contrast to ordinary communications systems, military communications systems must be designed with the presumption that they will operate in hostile environments. Consequently, special techniques that might be irrelevant or even harmful in ordinary communications are needed for communications systems that are to be viable on the battlefield." [Ref. 3: Preface]

Although military systems employ the same technology, and often the same equipment as commercial systems, the essential difference can be summed up in the catch-phrase "survivability." The military environment places constraints on the communicator which result in the fielding of systems with unique properties. Clearly not all equipment designed for military applications must operate over the complete range, of day-to-day peacetime operations and training through total nuclear war; but a reasonable and affordable compromise is certainly achievable [Ref. 4].

Both commercial and military systems suffer from the degrading effects of circuit properties and impairments. Tactical employment exposes military equipment to the worst of natural and man-made disruptions. The natural electromagnetic spectrum is inherently hostile, military systems are faced with the additional burden of enemy interference with circuit paths through intrusion or jamming. The tactical necessity for frequent movement; installation, tear-down, re-installation of systems, takes a toll in equipment casualties. Finally, there is the very real possibility of direct enemy attack upon command and control centers. If these assaults are successful, all or part of the communications system may be destroyed or disabled, thereby temporarily or permanently disrupting major portions of the communications capabilities.

The military communications system must survive to provide service to its users. This neccessitates a viewpoint on selection of equipment and system employment which maximizes survivability in a catastophically hostile environment. System survivability cannot be achieved by focusing solely on equipment. While it is certainly necessary that equipment withstand the exposure of the battlefield, a higher level, systems approach to survivability provides a more viable solution. The goal is to design and implement a system architecture which is robust in that it provides redundancy of both equipment and capabilities; offers rapid selection of a variety of alternate means; and is comprised of upwardly and downwardly compatible equipment. The envisioned solution in the Marine Corps is the architecture of the landing force integrated communications system (LFICS).

B. INTRODUCTION TO LFICS

The landing force integrated communications system (LFICS) presented in [Ref. 2: Chapter 5] is the defined architecture for the Marine Corps tactical communications network. It consists of all personnel, equipment, interface and data formats required for operation of a landing force communications system. LFICS is not a single system but encompasses all resources which enable FMF commanders to exercise command and control over assigned tactical forces in accomplishment of their mission. It includes a variety of circuit paths such as: single-channel point-to-point and netted radio, tactical digital information links (TADIL's), and switched/non-switched multichannel communications. LFICS provides the internal and external circuits required by the commander at each echelon. The achievable configurations are limited only by the needs of the commander and the available resources.

The ultimate goal is to configure the LFICS as a common-user network, which is conceptually equivalent to a typical nodal circuit switched network found in any of several sources in the commercial literature, such as in Stallings [Ref. 5: Chapters 1 and 8]. Reduced to its simplest form, a nodal circuit switched network can be explained as follows: two or more separate nodes which communicate (internodally) with each other over demand established circuits and internally (intranodally) provide services to a variety of local users. A demand circuit between users is established, remains active for the duration of the transfer (voice or data), and is then disconnected, freeing common resources for other network users.

1. Analog to Digital Transition

The transition of the LFICS from an analog to an all digital environment is underway. The projections of [Ref. 2] identify the near term period (1987-1990) as a hybrid analog and digital environment, and the long term period (1991+) as the target for complete transition to a digital environment.

In the near term period several new digital devices will be fielded. Since there will also be residual analog devices in service, the LFICS architecture and equipment must retain limited analog interface capabilities. In the long term, as the analog devices are totally replaced by digital devices, the analog interface capabilities will be eliminated from the transitional systems by removal of special pupose analog modules or the fielding of newer, all digital replacements.

2. Focus on a Generic LFICS Node

In the LFICS, a node is constructed at each major command and control center. As enumerated in [Ref. 2: Chapter 5] and shown generically as Figure D.3 in Appendix D. These nodes range in size from infantry battalion, artillery battery units, up through FSSG, MAW, MARDIV and MAF levels. When a LFICS node is viewed separately from its network, it exhibits certain characteristics which remain fairly constant regardless of the command level.

A node provides internal (intranodal) and external (internodal) communications services to its local users. The intranodal user-to-user connections are provided by manual, semiautomatic, and fully automatic switching of circuit paths. The internodal services are provided by a variety of single channel and multichannel radios, satellite terminals, and metallic or fiber cable systems, as appropriate. A LFICS node connects to one or more external nodes via these various transmission media. The resulting array of individually tailored nodes forms the LFICS network.

3. LFICS Employed as a MAF Network

As previously mentioned, the resources of the LFICS are employed in many ways to support the communications needs of the force commander. For illustrative purposes, the MAF structure can be used to provide insight into the functioning of the network. The LFICS network of Figure 2.1

shows the internodal connectivity and hierarchial structure of a typical MAF employment.

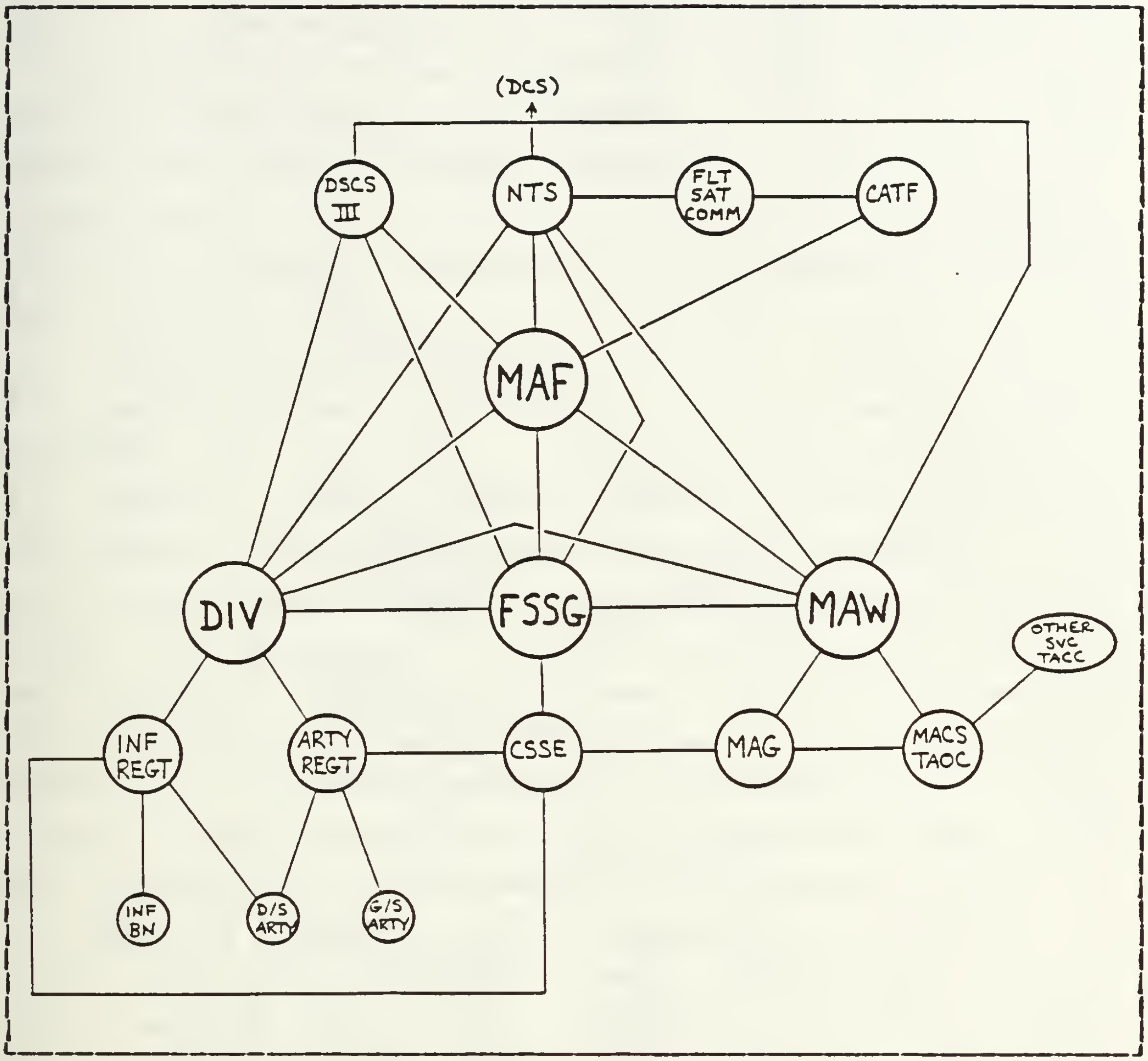

Figure 2.1 A Typical MAF Network.

Notice that there is an explicit extension beyond these Marine Corps organizations to the US Navy for entry in the Defense Communications System (DCS), Navy Tactical Data System (NTDS); and to other services and senior (Joint Command) nodes.

C. LFICS NETWORK FUNCTIONING

The example of Figure 2.1 illustrates the primary factors contributing to the survivability of the LFICS: redundancy of internodal connectivity, and alternate means of connectivity. The example MAF LFICS network exhibits what is known as fully connected or mesh topology for the major command and control nodes of interest in this study (those highlighted in Figure 2.1). It can be seen that survivability is enhanced by the topology and the loss of one or more nodes has little effect on the connectivity and functioning of the remaining portions of the network. All communications services provided by the underlying LFICS architecture are transparent. That is, the underlying network methodology and technology is of no concern to a user as long as there exists the capability to transfer data from one location to another. This is the essence of any effective communications system as data forms the basis of information[1] which is needed by each user to perform their respective tasks in the overall command and control environment. These information needs are often not well defined beyond interconnection at the network nodal level. This is of little consequence in a common-user switched network such as envisioned in LFICS as circuit paths are provided on a demand basis. The signals containing the data must be routed from an originating user data terminal equipment (DTE), via data communication equipment (DCE), to one or more receiving user DTE's. As shown from a nodal viewpoint in the flow chart of Figure 2.2, the path a signal follows from its origin to its destination within the network can be a choice among many alternatives. Any user terminal equipment which originates and/or receives data (or voice) is classified as data terminal equipment (DTE); likewise, any media and associated equipment item which functions as part of the circuit path between two (or more) users is classified as data communication equipment (DCE). The circuit path may be intranodal user-to-user, or may extend internodally to, or through, one or more distant nodes, to an ultimate destination.

---

[1] A point driven home by COMO Grace Hopper, USN, during her presentation at the Naval Postgraduate School on July 10, 1985.

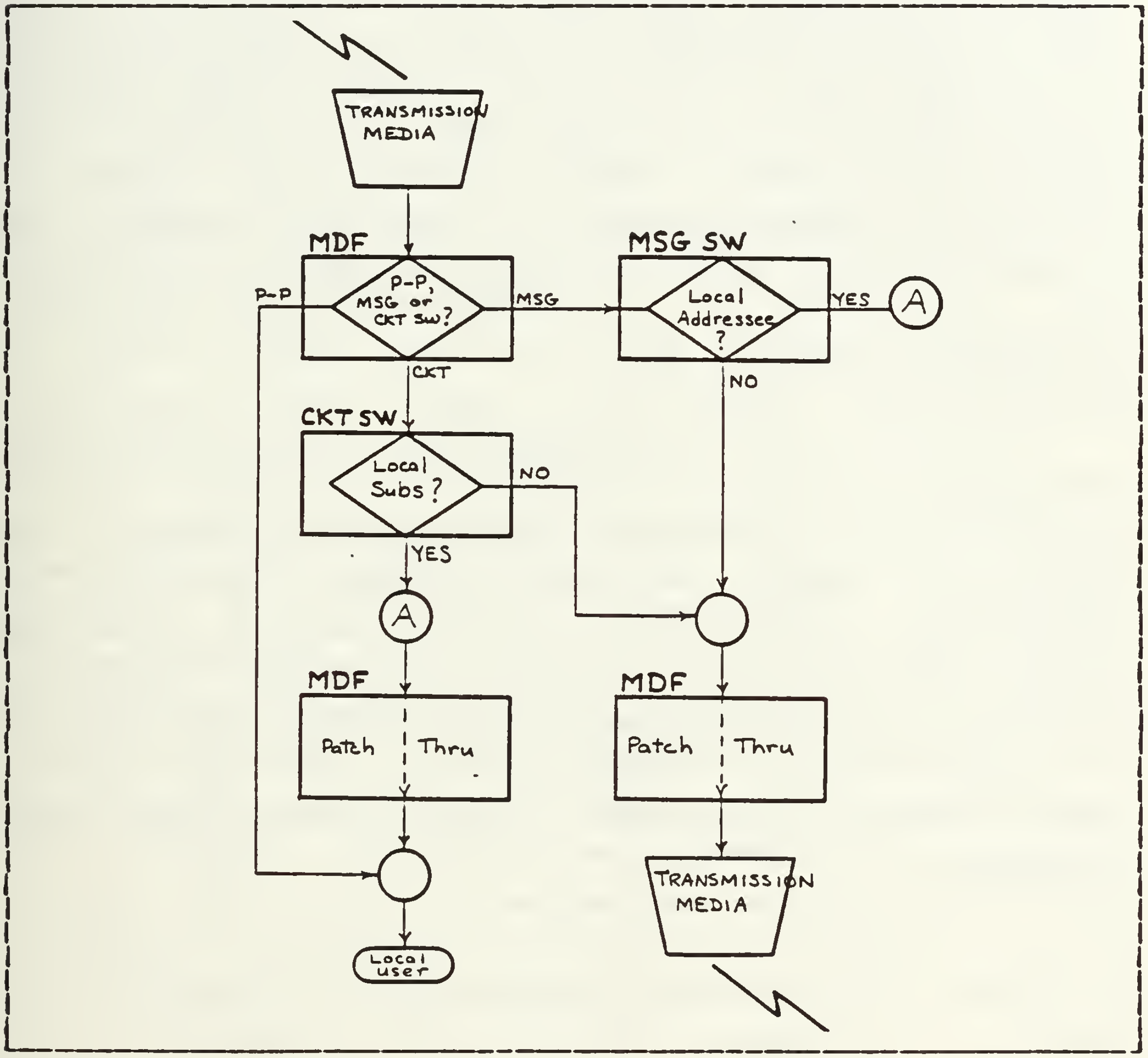

Figure 2.2 Signal Routing Within a Typical Node.

Signal routing decisions within the LFICS are made by: manual, semi-automatic or automatic circuit and message switching equipment; or by direct media connectivity. There is inherent in the DCE, the necessary conversion process (signal levels, rate, coding, ...) which provides compatible signals at the switching equipment, and at the DTE. This conversion may occur at the switch interface or in a sequence of DCE. Ultimately, all signals entering a node are processed, delivered to a local DTE, or retransmitted through the internodal media to a more distant node. It can readily be seen that as a signal path transitions from external DCE to internal DCE, or local DTE to local DTE, there exists a need for connectivity between the variety of transmission media and the local DCE/DTE. This connectivity is provided by a main distribution frame (MDF).

D. MAIN DISTRIBUTION FRAME

The main distribution frame (MDF) has as its primary function, the physical, metallic and/or electronic interconnection of all internodal transmission equipment, nodal circuit and message switching equipment, and local user terminals. The MDF exists, in some degree, at all nodal levels wherein user or switching (DTE/DCE) requirements dictate. The MDF provides a centralized circuit appearance for every item of DTE and DCE within the node and is an ideal location for exercise of LFICS communications control functions.

III. COMMUNICATIONS SYSTEM CONTROL AND MANAGEMENT

A. GENERAL

Communications control is a concept for overall control of available communications resources to provide the necessary responsiveness to the telecommunications needs of the force commanders. The employment of communications control concepts are appropriate at all levels, or nodes, of the landing force integrated communication system (LFICS) and are employed by an organic Communications Officer/Chief or more elaborate organization as discussed below. This study addresses primarily those nodes at MAF, MARDIV, MAW, and FSSG command posts as mentioned in the introduction. Each of these command and control or support organizations constitutes a nodal element in the overall LFICS architecture described [Ref. 2: Chapter 5].

More specifically, communications control (COMMCON) is a management organization whose tasks include the typical organizing, planning, directing, controlling, coordinating, and evaluating functions applied to communications personnel and equipment resources employed to accomplish the assigned missions and tasks. While the majority of COMMCON activity is intranodal, its responsibilities extend beyond the host node to senior, subordinate and adjacent nodes within the network. This internodal cooperation is essential to insure the proper management of joint responsibilities within the LFICS structure and the resulting network speed, reliability and flexibility. The overall organization of COMMCON consists of several elements and subordinate functional organizations. The identification of these elements and their missions is highly summarized in the following. For a more complete description, and a comparison with the joint service (TRI-TAC) equivalent terminology and functions, please refer to Appendix A.

1. System Control (SYSCON)

System control is a method for managing the communication resources for the effective and economical utilization of equipment and personnel resources and includes planning, engineering, determination and evaluation of requirements and restoration policies, centralized direction and control. SYSCON is subdivided into two main functional areas: system planning and engineering (SPE) and operational system control (OSC).

2. System Planning and Engineering (SPE)

The SPE plans for the implementation of the communications system.

3. Operational System Control (OSC)

The function of the OSC is to ensure that all available circuits are used to the best advantage in the dynamic force communication system. The OSC has an operational sub-element, the operational system control center (OSCC).

4. Operational System Control Center (OSCC)

The OSCC operationally manages, within prescribed limits, the communications resources through direct control of all personnel and equipment resources. The OSCC employs the technical control facility as the means of implementation of communications system plans and directives issued by the OSC.

5. Technical Control (TECHCON)

The TECHCON or TECHCON facility (TECHCONFAC or TCF) is the focal point and means of exercising centralized technical supervision and control over the installation, operation and maintenance of selected circuits. It provides for a common interface point (MDF) between nodal DTE users, DCE, and the various internodal transmission media; and provides a facility for performance of the required technical control procedures and tasks which implement the functions discussed in the following chapter.

The focus of the remainder of this study is on the needs and functions of technical control in the near term (1987-1990) hybrid analog and digital; and the long term (1991+) all digital LFICS environments. A detailed presentation of the existing TECHCON functional requirements from both the USMC and joint service viewpoints is found in Appendix A.

IV. TECHNICAL CONTROL OF AN ANALOG/DIGITAL NETWORK

A. GENERAL

The main distribution frame (MDF) has been defined and identified as the ideal location for performing network management and control functions. The control of a large network, such as a LFICS MAF employment, involves many managerial and technical aspects. Since the focus of this study is upon technical control, the following sections present general and specific discussion which address the question: What are the functions, procedures, tasks, and general characteristics of technical control in an analog and digital environment?

It is curious to note that industry is now seriously facing the same large-scale digital network management situation as we are in the military. That is, to decide what technical control functions are required, where it is located within the network, and how technical control accomplishes it functions. There is a wealth of discussion in both the commercial and military literature on this subject.[2]

1. General Technical Control Functions

There is nearly universal agreement between industry and the military on the basic technical control functions. While exact viewpoints differ semantically, such as: Lowry, Lester and Ogle [Refs. 6,7,8] and the military [Ref. 9: p. 2-1], their diversities can be aggregated and highly summarized as shown in Table 1 below.

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[2] The reader is referred to the sectioned bibliograpy for a detailed list of categorized references.

TABLE 1
GENERAL TECHNICAL CONTROL FUNCTIONS

Connectivity
Monitoring
Isolation
Restoral
Reporting

These functions are not very specific nor all inclusive but do form the basis for further discussion. Technical control functions should not be confused with the procedures and tasks which are required to implement them. While functions may be highly summarized and general, the resulting procedures and tasks are detailed. These procedures can be implemented in a variety of locations throughout the network and using a variety of techniques. The industrial-military community consensus is that nodal switching centers provide the appropriate sites for both circuit access and centralized control. As will be seen later, the term "centralized control" does not imply a singular facility without remote or redundant capabilities; but rather a focal point for the management and control of all technical activities. Circuit access is a critical factor and is the primary reason for selection of the MDF as this focal point. [Ref. 10]

The "how" of technical control is a much more detailed issue to resolve. There exist numerable misconceptions as to the differences between analog and digital technical control. The two are not mutually exclusive. All technical control functions which apply to analog systems apply equally to digital systems. It is the specific procedures and tests which differ between the two. As discussed by Leggett [Ref. 11], the foundations of the transmission of digital data are in the analog characteristics of the circuit media. The ignoring of these analog properties and potential impairments is equivalent to an assumption of analog perfection. This assumption is not acceptable. Except in the case of baseband transmission of digital data, all circuits must meet the minimum analog transmission media standards before the additional circuit requirements (if any) of high-speed digital data can be imposed. The technical control facility, AN/TSQ-84, is adequate in the strictly analog sense as presently required. It would require interface modifications to match its 26-pair cable connectors to coaxial or fiber optic cable systems if operated with the newer digital equipment. The additional testing required for the quantification of digital circuit properties and impairments is beyond our current capabilities.

These technical control functions, procedures and tasks are implemented through the application of appropriate test, measurement and diagnostic equipment (TMDE). The selection of this equipment is beyond the scope of this study. It suffices to point out that there is a broad spectrum of analog and digital TMDE available off-the-shelf from both standard military and commercial inventories. This variety of choice is based on the invariance of circuit physical properties and impairments across communications systems in both military and commercial applications. Analog and digital circuit properties and impairments are too detailed for the purposes of this study and will not be discussed. They were, however, examined as a by-product of the basic research and are summarized for the interested reader in Appendix B. Also presented in Appendix B is a summary of the LFICS signal characteristics in terms of connectivity, bandwidth, data rate, etc. Once the desired technical control facility is specifically defined, in a more detailed study, the selection from among the variety of TMDE will be based upon the equipment needs for the implementation of specific procedures and tasks relative to the circuit characteristics summarized in Appendix B.

2. Interoperability Considerations

It is a requirement stated in [Ref. 2: pp. 1-4 & 1-5] that all LFICS equipment be interoperable with other service and allied forces. The US Air Force is procuring the AN/TSQ-111 [Ref. 12] and the US Army intends to implement the AN/TTC-39A for service in the subject time periods. The Marine Corps, therefore, must consider the impact of our selection of technical control facility when required to operate in a joint environment. TRI-TAC is the joint service agency which is the proponent of this interoperability for US forces as well as NATO allied forces. If we deviate from the TRI-TAC standards, we place ourselves in a situation of relative isolation as far as joint circuit management and technical control. In the point-to-point mode of circuit diagnosis, each end of the path must have compatible suites of TMDE or we severely limit our capability to isolate and restore in a timely fashion.

3. Automation of Technical Control?

We often take the viewpoint that the most affordable approach to systems acquisition is to design and obtain only what we need to achieve the mission, often resulting in the implementation of manual procedures. This is a bottom-up approach to achievement of the threshold "mission capability" and often falls short in growth potential and in operations under degraded conditions. It assumes that we have completely defined all potential user information needs and requirements for the life of the emerging system. As mentioned by Pipho [Ref. 13] there is no Marine Corps enumeration of these user data needs. On the other hand, a viewpoint which takes a top-down approach will often settle at the same point of mission capability. But this approach provides a better feeling that redundancy, "excess capability", and growth potential needs have at least been examined systematically. Redundancy and excess capability provide some assurance that in a degraded mode of operation, we remain capable of achieving the mission. A classic case of excess capability is in the area of automation. Is automation necessary and how much is enough?

There is a definite direction indicated in both the military and industrial literature. That direction is toward fully automated technical control facilities. In Pigeon [Ref. 14], the thrust is described as an attempt to leave the era of the "fire fighting" or "If it's not broken, don't fix it" approach to technical control and progress to the predictive technical management realm through the use of automation. Military service efforts are also heading in this direction with the US Air Force development of the AN/TSQ-111, the US Army development of the AN/TTC-39A with technical control capabilities and our own planned enhancements to the AN/TTC-42 to provide automatic go/no-go monitoring of circuits.[3]

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[3] The US Army also experimented with an automated upgrade of the existing facility called the AN/TSQ-84A then decided not to pursue the project any further. A brief description of each of these equipments can be found in Appendix C.

It the past few years, the user community has demanded equipment that eases the maintenance burden by some degree of self-diagnosis. This built-in-test (BIT) and built-in-test-equipment (BITE) capability is easily implemented using rapidly advancing technology and miniaturization of components. The larger, more sophisticated equipments, are now microcomputer controlled and have the capability to assess their performance and report, via telemetry through off-band channels, to a central facility. These capabilities and the resulting status data are wasted if we lack a facility with the capability to receive, analyze, alarm, and react to the information which they provide.

As pointed out earlier, the other services are approaching the solution to digital technical control by the implementation of an automated facilty, the AN/TSQ-111 or AN/TTC-39A in the USAF and USA respectively. The industry trend is also toward an automated approach indicating that the technology will be forthcoming and the expertise will reside both in the government and in the private sector. In his thesis, Herrick [Ref. 15: **Introduction**] points out the shortcomings of a manual technical control facility from the viewpoint of negative effects on quality and timeliness; and the impact of limited personnel capabilities. The demands of an all-digital, high-speed data network can exceed the capabilities of the human operator to manually monitor and respond.[4]

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[4] As Kantowitz [Ref. 16: pp. 48-57] suggests: the probability of error of the human operator: begins slightly above the desired level at a low rate of task loading (rare tasks); then decreases as loading increases (learning); stabilizes about an optimum range; then increases asymptotically (approaches 1.0) as loading exceeds the capability of the operator. The argument then is that a computer would not suffer this loading phenomena of errors but remain consistent and stable across the spectrum of activity.

Arguments against automation often do not consider the situation from the viewpoint that the needs of the users are what determines the design and implementation of subsequent components. Correctly or not, we have already drawn heavily on automation as a solution to the maximization of our command and control capabilities. There are fielded and in development, several systems which utilize imbedded processors and require reliable high-speed data transfer to properly perform their command and control missions. These systems are and will become "users" of the landing force communications network.[5] The technical control facility, with its imbedded MDF, is at the heart of this system and its functional requirements are driven by the needs of these high-speed data users. Once we have fielded systems which demand the requisite circuit reliability, security, speed and flexibility inherent in their designs, we are unable to back down from the commitment to provide this necessary support. To focus only on manual technical control is to predetermine the capacity for a "reactive" only technical management mode and does a disservice to the network subscribers who expect dependable data communications.

On the other hand, too much automation can mean disaster in a severely degraded mode of operation. Equipment that is too sophisticated could become more of a burden to operate and maintain than the system it is designed to support. We must always maintain the capability to revert to manual operation in a degraded mode or in catastrophic failure situations (e.g.: loss of power, battle damage, ...). It is essential to include, by specification, manual and physical back-up capabilities when we select or design support systems such as a technical control facility.

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[5] These include systems such as: the Marine Integrated Fire and Air Support System (MIFASS), Tactical Combat Operations (TCO), Tactical Air Operations Center (TAOC), etc.

The technical control facility described in the following is assumed to be automated. It will contain provisions for a "failsoft" mode[6] with the explicit capability to manually, or semi-automatically operate all of the various elements in the TMDE suite inherent in the conceptual design; but the desired primary mode of operation will be automatic.

4. Levels of Capability

In a military application, we often discuss required versus desireable capabilities. These required capabilities are essential for completion of a successful mission. Other capabilities, which are desireable, are not required for a successful mission, but do contribute significantly to our ability to effectively manage and control the communication system. The loss of a desireable capability degrades the operation but does not cause mission failure. Let us now define four levels of capabilities: the first will represent all mission essential capabilities, the others, various degrees of enhancement beyond the mission critical needs. Descriptively, these desireable levels will be: minimum, nominal, and maximum; representing increasing capabilities beyond mission essential. The remaining discussion will be annotated with these levels <0>, <1>, <2>, and <3> respectively as follows:[7]

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[6] A capacity for graceful degradation from full operational capability to a more primitive mode. In essence, it will not crash catastrophically but degrade in controlled, logical increments.

[7] For example: a physical patch panel (such as the SB-4097) would be at <0> in both A/D systems; the existing AN/TSQ-84 would fall at <2> in an analog system and <1> in a digital system; while the developing AN/TSQ-111 would be

Level <0> - mission essential. Lack of a mission essential capability causes mission failure of the primary equipment (e.g.: technical control facility).

Level <1> - minimum. The minimum additional capability required to perform all of the procedures and tasks to implement functions stated at a minimum degraded level of operation.

Level <2> - nominal. The nominal or average capability desired to perform all of the stated procedures and tasks to implement functions in a manual, semi-automatic mode.

Level <3> - maximum. The capabilities required to perform all of the stated procedures and tasks to implement functions in a fully automatic mode, with manual operation as necessary.

B. TECHNICAL CONTROL ASSUMPTIONS

Prior to a discussion of the more specific functional and procedural requirements of technical control in the LFICS switched network, there are certain underlying assumptions which must be stated. These are made with the intent of avoiding later misunderstanding and to remove the burden of needless detail and inter-relationships in the following.

The technical control facility (TCF) of interest will be employed at MAF, MARDIV, MAW and FSSG (and MAB) level nodal LFICS elements. For this reason, and to meet the USMC standardization requirements, the TCF will have certain inherent minimum characteristics which are stated here as required without extensive justification:

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at <3> in both.

1. Main Distribution Frame (MDF) - the primary MDF will be located within the TCF and will provide the connectivity between the internodal circuits and DCE; and the intranodal circuits, DCE and DTE. This does not preclude the operational employment of an alternate MDF for contingencies.

2. Shelterized - the TCF will be contained in a standard military shelter, such as one of the S-280/G variety. Since the resulting TCF is a direct replacement for the existing AN/TSQ-84, there is no impact upon transportability.

3. Power - the TCF will have a requirement for power in all but its most seriously degraded operational mission essential mode. This requirement is estimated to be approximately 30 KW based upon similar facilities.

4. Requisite DCE/DTE - the TCF will be equipped with a requisite suite of DTE (telephones, TTY terminal, ...) and DCE (modem, multiplexor, data buffer, encryption device, ...) which are compatible with the fielded nodal circuit switching and terminal equipments and in sufficient variety as appropriate to the accomplishment of the required functions. This is particularly necessary at levels <2> and <3> for establishment of an equal level interface between signals. At other levels, the TCF can, in a degraded or mission essential mode, be effectively null and pass all circuits through without signal conversion action or any effect other than physical or metallic connectivity.

5. Environmental - the TCF will be equiped with environmental control units (ECU/air conditioners) and

required collective protection equipment (CPE) to enhance the survivability of both its human operators and any resultant suite of test, measurement and diagnostic equipment (TMDE); conditioning equipment; and computing equipment. These ECU and CPE will function in all but its most seriously degraded operational mission modes.

6. Personnel - the existing T/O provides adequate personnel for operation of the existing TCF. It is anticipated that this will remain true for the newer TCF. However, the personnel quantity and skill levels is not a function solely of the resulting TCF system design but on the overall complexity of the nodal and network system. Personnel and training issues will not be discussed in this study.

7. Quantity - there will be one TCF in each of the major nodes mentioned. This dictates that a total of 12 units will be modified or procured for operational LFICS use and additional units (as required) for training of operating personnel and maintenance technicians.

C. TECHNICAL CONTROL FUNCTIONS AND PROCEDURES

1. Expanded Description of Functions

The following are more specific discussions of the required functions of technical control (procedures are discussed later). Included in each function description is the implied coordination with senior, adjacent and subordinate technical control facilities.

a) Connectivity - the technical control facility will include the main distribution frame (MDF) function.

This MDF will provide connectivity of all circuits including: metallic (2-W, 4-W, 26-pair, coaxial cable), fiber optic, or radio circuit media which carry analog or digital signals between all intranodal equipment (DTE and DCE) and internodal transmission media (DCE). The connectivity will remain in the absence of power (i.e.: a physical, or metallic connection). The logical network connectivity, or routing algorithm is implemented in the switching equipment.

b) Monitoring - the technical control facility will include the capability to passively monitor (without circuit interruption or degrading effect) all circuits which pass through the MDF to detect impairments and degradation of transmission media and equipment. This enables the implementation of a predictive mode of technical control [Ref. 17: pp. 344-345]. This monitoring is solely to detect deradation or outage as reflected in the electrical properties and impairments of each circuit. It is not performance monitoring in the sense of collection of system statistical data such as: holding times, traffic flows, primary and alternate routings, etc. These latter forms of monitoring are best accomplished by the switching equipment.

c) Isolation - the technical control facility must have the capability to emply appropriate troubleshooting procedures to logically isolate to a portion or portions of the circuit path and/or equipment as being the cause of circuit degradation or failure.

d) Restoral - the technical control facility will have the capability to restore circuits to service once it is determined that there is an outage or sufficient degradation as to prevent effective usage of that circuit. This can include electronic corrective measures applied to the circuit media (line conditioning) as well as the insertion of spare or standby media and equipment as replacements.

e) Reporting - the technical control facility will maintain records, circuit logs, circuit status, etc., as required by the Defense Communications Agency (DCA) and locally approved regulations. The TCF will report as required to the controlling operational system control center (OSCC).

2. General Procedures for Implementation of Functions

The following describes in broad terms how a technical control facility would implement for provision of the desired functions at the various levels <0> to <3> of mission capability:

Level <0>: mission essential operation only. Connectivity is accomplished by the physical connections of the MDF. Monitoring is limited to the application of hand-held, battery powered, test equipment (such as a multi-meter, signal/noise meter, field telephone, ...). There is not a significant capability for quantification of test results. Isolation is a manual process of monitoring circuits in point-to-point or loop-back[8] mode using the same test equipment mentioned earlier with coordinated and controlled troubleshooting techniques. The circuit performance is verified in segments of ever increasing distance from the MDF until a point is reached where the degradation or failure is introduced and therefore evident. The circuit media or equipment fault is then isolated. Restoral is accomplished by the replacement of a faulty media or equipment component by patching of spare or standby equipment; or actual removal and replacement of the entire failed component by a trouble team. Reporting is done by telephone or messenger and records are maintained by manual means.

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[8] Point-to-point testing is the application of similar equipment at each end of a circuit; loop-back requires the distant end of the circuit to patch transmit to receive and vice-versa.

Level <1>: minimum enhancement above mission essential operation. Same as level <0> except the monitoring capabilities are enhanced by the addition of in-line parallel extensions to the MDF and by the application of an MDF/TCF mounted suite of analog TMDE (oscilloscope, spectrum analyzer, ...) which is employed using manual or semi-automatic procedures on selected circuits. There is a significant capability to quantify analog and some digital test results. Restoral capabilities are enhanced by analog circuit line conditioning equipment (line amplifiers, attenuators, delay envelope equalizers, ...) which allow the correction of certain quantified analog circuit properties to within acceptable standards. Reporting remains the same. Reliable power is required for the implementation of level <1> activities.

Level <2>: nominal enhancement above mission essential operation. Connectivity remains the same. Monitoring is accomplished by the application of a more sophisticated suite of TMDE which includes both analog and digital test instruments (e.g.: oscilloscope, spectrum analyzer, bit-error-rate (BER) tester, ...) to selected circuits using manual or semi-automatic techniques. Quantified analog and digital results can be used in restoral efforts. Isolation procedures remain essentially the same. Restoral capabilities are enhanced by the addition of digital circuit conditioning equipment (amplifiers, attenuators, delay envelope equalizers, ...) which allow the correction of certain quantified circuit properties to within acceptable standards. Reporting remains the same.

Level <3>: maximum enhancement above mission essential operation. An on-line computer is added with a bus compatible suite of computer controlled TMDE, and an electronic crosspoint matrix. Connectivity is provided by the electronic, computer controlled, crosspoint matrix with physical patching as a backup. Monitoring is accomplished by a suite of computer controlled, multi-purpose, analog and digital TMDE (such as: spectrum analyzer, BER tester, ...) which will provide alarms to the operator when an analog or digital circuit is degraded beyond tolerances or a failure occurs. Isolation is essentially the same as earlier but the point-to-point examination of a circuit may be performed by two TCF computers with the results and recommendations presented to the TCF operator for action. Restoral can be accomplished automatically by the controlling computer (within certain preset guidelines), semi-automatically by specific operator action at a keyboard, or manual patching actions. Reporting and status data collection involves data flow into and out of the TCF via telemetry channels from the various DCE/DTE, processing at the TCF and subsequent reporting to the controlling OSCC/OSC.

D. SUMMARY OF DESIRED TECHNICAL CONTROL IMPLEMENTATION

1. Technical Control Functional Implementation

Together with the above assumptions regarding the MDF, shelterization, power, requisite equipment, and environmental equipment, and given the various levels of capability enumerated above, the following is a level annotated top-down summary of the desired and required technical control functions and possible means of implementation:

Connectivity:

<3> The MDF is a computer controlled, equal level,[9] crosspoint matrix which connects nodal DTE/DCE to the internodal transmission DCE. Additional resources are included as on-line standbys for restoral procedures.

<0> A physical or metallic MDF patch capability for both analog and digital signals provides back-up in the event of loss of power.

Monitoring:

<3> A computer controlled suite of analog/digital TMDE is applied to the nodal circuits using either continuous or statistical selection methodologies.[10]

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[9] Analog and digital signals are made compatible prior to their appearance at the "equal level" patch matrix. Note that signals are not converted to equal levels if they require no technical control action other than connection to a suitable media. Equal level implies all necessary conversion: A/D conversion, multiplexing, encryption, data rate, buffering, etc.

[10] Continuous - all circuits are scanned periodically; statistical - selected circuits are scanned more frequently (higher priority) and/or some circuits are managed on a fix-when-failed basis (low priority).

<2> This same TMDE can be operate manually or semi-automatically for critical assessment of an identified circuit degradation or failure.

<0> Battery powered test equipment is utilized to monitor performance on selected circuits.

Isolation:

<3> The resident computer continuously monitors telemetry data from the various DTE/DCE for unusual conditions, interacts with other technical control computers, analyzes the results, and makes recommendations as to the location of a faulty component of either media or equipment.

<2> Location of a faulty or degraded component of either media or equipment is accomplished by application of the suite of TMDE using manual, or semi-automatic procedures in point-to-point or loop-back modes.

<0> Identification of the failed or degrade equipment or media component is accomplished by the application of battery powered test equipment.

Restoral:

<3> The resident computer makes crosspoint changes automatically (within preset guidelines), upon operator approval, or by operator initiated action at a keyboard (assumes a pool of spare resources is available).

<0> The operator makes physical patching changes on the MDF.

Reporting:

<3> The nodal DTE/DCE report to the TCF computer via telemetry. This information is summarized in an on-line TCF data base which is a record of all operator actions, alarms, restoral efforts, etc. It is also an on-line station and circuit log used later to construct reports, summaries, etc. The TCF reports to its controlling OSCC/OSC via computer link.

<2> The TCF reports to its controlling OSCC/OSC manually by telephone or written means.

2. Technical Control Block Diagram

Now that the assumptions, functions and procedures of technical control have been outlined in general and more specific terms, a technical control facility block diagram can be constructed. Figure D.2 in Appendix D will represent the desired ideal technical control facility during further discussion. The basic diagram is borrowed from [Ref. 18: p. 14-3], simplified, and improved with the additional resources and capabilities discussed earlier (central processor, computer controlled TMDE, ...).

V. ALTERNATIVE SOLUTIONS TO DIGITAL TECHNICAL CONTROL

As a result of this and any subsequent study, there are two decisions required. We must select the preferred means for implementation of the required technical control functions and procedures for both the near and long term. The long term decision is dependent upon the near term decision, that is, it is a compound decision. Once the solution for the near term is selected, the long term solution uses that choice of equipment as a minimum baseline for future use. This compoundedness will be discussed and resolved in the following chapter. The criteria for each situation are different due to both the relative time periods and the mixtures of fielded equipment. These differences will be mentioned, as appropriate, in the following discussion.

A. UNDERLYING LFICS ASSUMPTIONS

There have been actions taken to include limited technical control capabilities in the AN/TTC-42 (Enhanced). The Command and Control Master Plan [Ref. 2: p. 1-29] points out that:

> ". . . AN/TTC-42 (Enhanced) replaces both the AN/TTC-38 (analog) circuit switch and the AN/TSQ-84 communications control center and will perform both circuit switching and technical control functions."

In a subsequent remark [Ref. 2: p. 1-31], it is also mentioned that the SB-3865/TT will have limited technical control capabilities. This could be interpreted either as a desire to make the circuit switch into a fully capable, combined switching/multiplexing/technical control facility as discussed by Waxman [Ref. 19] or as a means of providing a redundancy of limited technical control capability in the nodal switching center. In the former case, our requirement for an additional technical control facility is limited to services provided to selected circuits which do not pass through the circuit switch (if any) and can consist of a minimal facility. In the latter, our requirement is for a complete analog and digital technical control facility which is separate from the switching equipment.

During the movement and assault phases, the unit level circuit switches (ULCS) operate in support of landing force troop spaces and activities independent of a technical control facility. Their inherent limited technical control capabilities can be used to advantage in this environment. Once ashore, in a more stable and demanding environment (due to the density and variety of users), the technical control capabilities of the circuit switches become inadequate.

The LFICS configurations are dynamic, changing rapidly as dictated by mission and tactical requirements. We must provide for the contingency of loss of a major circuit switch and the resulting need for rapid reconfiguration, and capabilities such as: analog to digital conversion, multiplexing, encryption, data buffering, etc. In this circumstance, the need for a separate, centralized technical control and main distribution frame becomes more apparent. Additionally, since the concentration of all technical control capability in one location is unwise in a hostile tactical situation, we may conclude from this that we require both the circuit switch capabilities and a separate, fully capable and redundant technical control facility. The redundancy can be employed in a primary role as the focus of technical control management or in a secondary role, as a critical back-up capability in support of the more primitive remote circuit switch or terminal equipment capabilities. The switch and terminal equipments can be employed as patch and test facilities (PTFs) with centralized control at the main technical control facility in agreement with the joint service approach to COMMCON discussed in Appendix A.

Finally, there is an assumption of normality in the design and implementation of any system. That is, we assume that the majority of its operation will be under normal or near normal conditions. We do, however, have to plan for the worst possible situation in the military environment. It is easy to visualize operation in a most severely degraded mode where subscribers would be directly connected to a transmission media and required to perform their own circuit monitoring, isolation and restoral actions. This would occur in cases of severe battle damage or catastrophic failure of the technical control facility, MDF, circuit switch or message switch. In short, we must plan for the worst yet hope for the best; and know our capabilities and implementation scheme at each extreme and in the middle ground. As much as possible, we must plan for a graceful degradation when it becomes necessary to do so. The gracefulness of this transition from normal to degraded modes depends on the location of the outage, and the capability of the technical control facility to respond with circuit rerouting, replacement of lost equipment with spares, and restoral of any necessary lost signal conditioning or processing capabilities.

B. CENTRALIZED/DE-CENTRALIZED CONTROL OF TECHNICAL CONTROL

There is no doubt that centralized control and coordination of technical control activities is desired as a primary goal. This approach is supported by both the military and commercial communities as it has the obvious advantage of providing a focal point for all technical management activities. There is the possibility, due to battlefield conditions, that a centralized facility is not feasible, we must then have the capability to temporarily revert to de-centralized technical management.

In a degraded state, we must have provision for de-centralization of the management technical control. This capability will be present in the circuit switch and in the various radio sets and terminals. It means simply that the operators of these PTFs will be required to independently manage their portion of the network until normal operating conditions can be restored. They will be provided the capability to perform (in some limited degree) the functions of technical control as stated in a previous chapter. Since this is not the preferred method of management of technical control activities, every effort should be made to re-establish a centralized facility as soon as possible after the outage or damage is corrected. It is best to plan for an alternate MDF/TCF to make this transition as quickly as possible thus regaining centralized technical control of the system.

C. CONTROLLED EXECUTION OF TECHNICAL CONTROL ACTIVITIES

Centralized control, as discussed above, is not meant to imply that technical control capabilities do not exist elsewhere in the nodal architecture. Aside from the issue of how control of TCF activities is organized, the actual functions themselves may be centralized or decentralized. Since certain LFICS DTE/DCE will have inherent technical control capabilities, it would be advantageous to distribute the TCF workload as much as possible to these patch and test facilities (PTF). While their capabilities are limited by comparison, they can be utilized to relieve the primary TCF from more the mundane tasks, especially in a crisis situation. As discussed in Appendix A, these PTF's can also be referred to as communication-electronics system elements (CESE's), whose activities are controlled by the primary TCF (or CNCE-T). This distributed but centrally controlled activity also provides for continuity of technical control activity if the primary TCF is lost due to outage or battle damage. On the other hand, if a PTF's capabilities are lost, there must be a centralized capability in the TCF to provide redundancy and the desired continuity.

We desire a perfect blend of minimum capability consistent with the achievement of the communications mission, and the capability to continue operation in the presence of major DCE (e.g.: circuit switch, radio terminal, ...) damage, the solution is a level of redundancy. This leads to the conclusion that what we require is a primary and secondary capability at different sites. We have already seen that PTF's are somewhat capable, but they are not candidates for primary TCF functions. It is then apparent that we must establish a fully capable and redundant primary TCF with the PTF's as secondaries, in full agreement with initial TRI-TAC system concepts. The selection of this primary facility will be done in the subsequent discussion and decision processes. The several alternatives are discussed below.

D. CENTRALIZED TCF ALTERNATIVES

The following items of equipment are identified as the primary range of choices to meet the needs of the Marine Corps for the centralized primary technical control facility. Their sequence of presentation implies no preference at this point. There is a summary of the more specific capabilities of each found in Appendix C and system level block diagrams in Appendix D. As will be seen in the next chapter, there are differing criteria for selection in the near term vice the long term. The alternative technical control facilities are:

1. US Air Force Facility (AN/TSQ-111)

The AN/TSQ-111 (Variant) is the US Air Force communications nodal control element (CNCE). It was originally the joint service (TRI-TAC) approach but the US Army and Marine Corps have deferred from active participation in its development and procurement. The TSQ-111 was designed and built to perform the functions of technical control in an automated mode with a manual capability as back-up. It has demonstrated its capabilities and is compatible with all TRI-TAC user, switching and terminal relay equipment. It has completed developmental and operational testing (DT/OT-III) successfully with deficiencies noted in: reliability, availability and maintainability (RAM), software, safety, human engineering and dynamic memory [Ref. 20: p. xii]. It is assumed that these deficiencies can and will be corrected thereby making the TSQ-111 a viable alternative choice for the long term. There is too little lead time and high acquisition risk (quantity, schedule) to consider it as a viable USMC alternative for the near term.

2. US Army Facility (AN/TTC-39A)

The US Army approach to the problem is the enhancement of their planned AN/TTC-39A circuit switch to provide technical control capabilities. These equipment capabilities were extracted from the AN/TSQ-111 and installed in the TTC-39A. The TYC-39A was designed with the capacity to support a US Army corps area in a single or multiple shelter configuration. It is a larger, compatible version of the TTC-42 already planned for USMC use. Due to its intended employment at corps level, the TTC-39A is not viewed as a viable Marine Corps alternative solution in either the near term or long term but will be included as an alternative as a means of validating the decision processes.

3. Planned USMC Circuit Switching Facility (AN/TTC-42)

The AN/TTC-42 circuit switch will have analog and digital capability, and limited technical control capabilities. There is a patch panel, automatic monitoring of trunk circuits is performed on a go/no-go basis, but there is no line conditioning capability. Its availability in the near term makes it a viable candidate if we are willing to accept its primitive and limited technical control capabilities. It could be employed alone, with a primitive MDF, with the existing AN/TSQ-84 or the several various AN/TSQ-84 modifications dividing the total mission into the analog and digital tasks best suited to both.

4. Analog and/or Digital MDF

It would be possible to implement a level <0> capability at an MDF for analog and/or digital circuits. The existing SB-4097/U is essentially an analog MDF. A hybrid analog/digital MDF could be constructed to interface with both 26-pair and coax directly or through separate converters. This could be achieved for the near term. Its applicability in the all digital long term is doubtful.

5. Existing USMC Facility (AN/TSQ-84)

The existing facility is acceptable for use with analog circuits but is unacceptable for use with digital circuits beyond simple connectivity (26-pair compatible). Its 26-pair cable interface is not compatible with the circuit switch coaxial connections nor the coaxial media from a tactical data system, message terminal or multiplexed user group. To be acceptable at a minimum level of digital connectivity, the existing TSQ-84 would require interface modifications. It has analog test and conditioning equipment but has no equivalent digital equipment. The TSQ-84 is a viable near term solution for analog circuits when employed with the TTC-42 providing limited digital technical control services.

6. Existing USMC Facility with Interface Modifications

The existing facility with interface modifications to permit the entry of signals from coaxial cable systems (and ultimately, fiber optics) would be a viable alternative in the near term and perhaps the long term. These modifications could be external or internal to the shelter. The resulting AN/TSQ-84(M1) would have the capability to perform at Level <2> for analog circuits and Level <1> for digital circuits.[11] With careful planning and management, the degrading effects of high data rates on the 26-pair portion of the circuit path can be minimized or avoided. Employment of the TSQ-84(M1) together with the TTC-42 (Enhanced) provides a blend of reduced digital capability but highly adequate analog capability for the near term.

7. Modified USMC Facility with Added Digital Capability

The modification of the AN/TSQ-84 beyond its interface would include the addition of selected items of digital test equipment. Let this next stage of modification be referred to as the AN/TSQ-84(M2). The combination of the existing analog equipment and new digital test equipment would provide adequate capability for the near term. It would also be advantageous to include more permanent shelter interface modifications for both coaxial and fiber optic cable systems.

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[11] The oscilloscope can be employed as digital test equipment to display an "eye pattern" as discussed by Lowry. [Ref. 21]

8. Upgraded USMC Facility with AN/TSQ-84A Kit

The US Army developed and experimented with a modification kit for the TSQ-84. When installed, the result is the AN/TSQ-84A (Upgraded). The facility is essentially a computer assisted, semi-automatic and manual analog TCF. It underwent extensive field testing which demonstrated that the concept was good but there were several problem areas: operation at high and low temperature extremes, reliability, maintainability, safety, software, and technical publications. The Army prepared 25 kits, fielded five, leaving 19 currently at the Tobyhanna Army Depot. Assuming that their deficiencies are correctable, the application of these kits to our 12 existing AN/TSQ-84's would be a viable solution for the near term. The kits could also be applied to the AN/TSQ-84(M1) and (M2) modified TCFs mentioned above. The applicability of the AN/TSQ-84A, -84A(M1) or -84A(M2) in the long term would depend on their performance during the near term period, if selected.

9. New Start Digital TCF (AN/TSQ-xxx)

The final alternative would be the unilateral USMC design and procurement of an entirely new AN/TSQ-xxx facility. Our policy is that this is to be undertaken only as a last resort [Ref. 2: p. 1-4]. The decision to build a new start would have the benefits of the lessons learned by the other services, new technology, elimination of unneeded capabilities, inclusion of capabilities non-existant in other equipments, etc. While this solution may appear more costly, there are potential inherent cost savings in the application of emerging technology not in existance when the

AN/TSQ-111 or AN/TSQ-84A concepts were conceived and developed. Therefore, in the event that the "off-the-shelf" TSQ-111, TSQ-84A, and all other alternatives prove inadequate, and considering the necessary acquisition lead time, the construction of a new facility is viewed as a viable alternative for the long term only.

E. SUMMARY OF ALTERNATIVES

The several alternative technical control and switching equipments discussed above, when operated alone or in combination, form the alternatives summarized below. The AN/TTC-42 is implicitly employed as a switching facility (except alternative "1"). When mentioned here, it is being employed specifically as a limited technical control facility. System level block diagrams of each alternative implementation are shown in Appendix D. The numbering scheme shown here will remain constant for the remainder of the study. The alternatives are:

1. AN/TTC-39A - replace the AN/TTC-42 (Enhanced) with the AN/TTC-39A and utilize its enhanced technical control capabilities (Fig. D.4).

2. AN/TTC-42 (Enhanced) - use the circuit switch unilaterally as an integrated switch, MDF, and technical control facility for all analog and digital circuits [Ref. 19] (Fig. D.4).

3. AN/TTC-42 (Enhanced) and analog MDF - use the circuit switch as both switch and limited primary technical control facility but include a remote analog MDF with a level <0> capability for all analog circuits which do not pass through the switch (Fig. D.5).

4. AN/TTC-42 (Enhanced) and hybrid MDF - use the circuit switch as both switch and limited primary technical control facility but include a remote analog/digital MDF with a level <0> capability for all analog and digital circuits which do not pass through the switch (Fig. D.5).

5. AN/TTC-42 (Enhanced) and AN/TSQ-84 - use the circuit switch as both switch and limited primary technical control facility for digital circuits and the existing AN/TSQ-84 as a level <2> primary technical control facility for all analog circuits (Fig. D.6).

6. AN/TTC-42 (Enhanced) and AN/TSQ-84(M1) - use the circuit switch as both switch and limited primary technical control facility for most digital circuits and the modified AN/TSQ-84(M1) as a level <2> primary technical control facility for all analog circuits and level <1> secondary facility for all remaining digital circuits (Fig. D.6).

7. AN/TTC-42 (Enhanced) and AN/TSQ-84(M2) - use the circuit switch as both switch and limited primary technical control facility for some digital circuits and the modified AN/TSQ-84(M2) as a level <2> secondary technical control facility for both all analog circuits and for most digital circuits (Fig. D.6).

8. AN/TTC-42 (Enhanced) and AN/TSQ-84A - use the circuit switch as both switch and limited primary technical control facility for digital circuits and the AN/TSQ-84A as a level <2> primary technical control facility for all analog circuits (Fig. D.6).

9. AN/TTC-42 (Enhanced) and AN/TSQ-84A(M1) - use the circuit switch as both switch and limited primary

technical control facility for most digital circuits and the modified AN/TSQ-84A(M1) as a level <2> primary technical control facility for all analog circuits and level <1> secondary facility for all remaining digital circuits (Fig. D.6).

10. AN/TTC-42 (Enhanced) and AN/TSQ-84A(M2) - use the circuit switch as both switch and limited primary technical control facility for some digital circuits and the modified AN/TSQ-84A(M2) as a level <2> secondary technical control facility for both all analog circuits and for most digital circuits (Fig. D.6).

11. AN/TTC-42 (Enhanced) and AN/TSQ-111 - use the circuit switch as switch and patch and test facility (PTF) and the AN/TSQ-111 as a level <3> automated technical control facility for all analog and digital circuits (Fig. D.7).

12. AN/TTC-42 (Enhanced) and AN/TSQ-xxx - use the circuit switch as switch and patch and test facility (PTF) and the AN/TSQ-xxx as a level <3> automated technical control facility for all analog and digital circuits (Fig. D.7).

Recall that since the near and long term decisions are compound, the selection of alternatives for the long term will be reduced to a set which includes only those choices of equal or greater functional capacity than the equipment chosen for the near term. This analysis takes place in the next chapter.

VI. AN APPLICATION OF MULTICRITERIA DECISION THEORY

A. DEFINITION OF THE REQUIRED DECISIONS

As mentioned in the previous chapter, there are two required decisions:

1. Select a near term solution to meet the needs of technical control in a hybrid analog/digital LFICS environment which will exist in the 1987-1990 era.
2. Then, based on the near term selection and additional analysis of the long term alternatives, choose the preferred solution for implementation in the long term (1991+) all digital LFICS environment.

It is essential to note that the long term selection is dependent on the near term choice. The selection for the near term establishes a capabilities baseline which the long term choice must meet or exceed. The following application of decision theory will proceed with the near and long term alternatives evaluated in parallel for simplicity and continuity of the presentation. The effects of dependence will be assessed upon completion of the process by analysis of the results and appropriate elimination of any inconsistent results.

B. SUMMARY OF THE CRITERIA, APPROACH AND TECHNIQUE

1. Presentation of the Criteria

The selection of the criteria for evaluation of the alternatives is critical to the stability of the eventual decision. This stability means that a decision made at this point, with limited information, will remain a good decision in the future in the presence of more perfect information and/or different criteria. The goal of this initial study is to provide a reasonably adequate but constrained set of equivalent (or "weakly" ordered) evaluation criteria to achieve a relatively stable decision. A search for differing criteria in class lecture notes, Marine Corps policy [Ref. 2: pp. 1-4 to 1-7], consultation with other Marine Corps and Army communications officers and a review of the literature, yielded the list shown in Appendix E. Selection of criteria from this list was based on applicabililty in the conceptual phase, available data for assignment of values, present and future generality, and the author's preferences based on experience. The resulting criteria are specified in the following discussion.

As mentioned above, there are two decisions to be made, each having different criteria. In the near term, the focus is upon timeliness and ability to perform a hybrid analog/digital mission. While in the long term, the focus is more generalized to include an examination of the all-digital facility and the normal systems acquisition considerations which are appropriate to the available lead time.

a. Near Term Criteria

The criteria for the near term decision are listed below. They will be treated as equivalent with a top to bottom "weak" preference imposed only as required. The associated codes will be used for abbreviation in later tables and discussion.

- Timeliness/Availability. (T/A) is an assessment of the proposed alternative's equipment availability to the Marine Corps for service in the near term period. Uses scale: poor-excellent. Off-the-shelf items would be classified excellent, items classified toward the poor extreme would be under development, or in production but of high risk in schedule or quantity.

- Analog Performance. (AP) is the level of capability for an analog mission. Uses levels: <0> - <3> discussed earlier.
- Digital Performance. (DP) is the level of capability for a digital mission. Same scale as for AP above.
- Cost. ($$) is a ranking of the expected cost to implement the alternative in the near term. Uses scale: low to high.

b. Long Term Criteria

The criteria for the long term decision are listed below. The will be treated as equivalent with a top to bottom "weak" preference imposed only as required. The associated codes will be used for abbreviation in later tables and discussion.

- Digital Performance. (DP) same as mentioned earlier.
- Analog Performance. (AP) same as mentioned earlier.
- Manual back-up capability or "failsoft." (MBU) is an assessment of the alternative's ability to gracefully degrade, without permanent damage, and adequately function in a seriously degraded mode (no power or loss of processor) using all manual procedures. Uses scale: poor-excellent.
- Standard USMC/off-the-shelf. (STD) is an assessment of the standardization of the alternative. Uses scale: poor-excellent. Off-the-shelf USMC equipment would

score excellent, other service off-the-shelf would score good, and so on until non-standard, new designs would score poor.

- Interoperability. (IOP) is an assessment of this alternative's ability to interoperate with other joint service and allied technical control facilities. Uses scale: poor-excellent. TRI-TAC equipments would score higher than others.
- System complexity index. (SCI) is a classification of this alternative system's complexity in comparison to the others. Uses scale: low-high. A Low rank (high value) is assigned to a simpler manual system.
- Technological Risk. (TR) is an assessment of the risk involved in use/development of this alternative item or system. Uses scale: low-high. Items for which technology exists and has been demonstrated will score low, while items to be developed employing concepts not yet tried will score high.
- Timeliness/Availability. (T/A) same as mentioned earlier but for long term.
- Planned upgrade to all digital. (PIP) is an assessment of the adaptability of this system to an all digital upgrade in the future. Uses scale: poor-excellent. Equipment designed for digital use but retro-fitted with analog capability would score excellent while equipment requiring extensive modification would score poor.
- Cost. ($$) same as mentioned earlier but for long term.

2. Discussion of the Ordinal Scale Values

Prior to any analysis of the alternatives, they must be assigned values for each criteria. These values, or attributes, can be on nominal, ordinal, interval or ratio scales of increasing sophistication. A nominal scale of measurement uses numbers merely as a means of separating the properties or elements into different classes or categories (e.g.: Democrat, Republican; low, medium, high; etc.). An ordinal scale of measurement refers to measurements where only the comparisons "greater," "less," or "equal" are relevant between values (e.g.: 1-first, 2-second, 3-third, etc.). An interval scale of measurement considers not only the order of the measurements (as with ordinal), but the relevance of the size of the interval between measurements (e.g.: temperature in degrees F or C where zero is arbitrary). Finally, a ratio scale is used when not only the order and interval size are important, but also the ratio between measurements (e.g.: weight, distance, etc., where zero is constant).

The alternatives in this study will be assigned values on several criteria. It is conceivable that a mixture of each of the scales mentioned above could be employed. This choice is based upon the scale of available data relative to the various alternatives on the dimension (criterion) of interest. When some alternative's attributes are well known at an interval or ratio level but one or more of the other's are not, we must digress to the scale which produces compatibility between the alternatives, usually ordinal or nominal.

It is the case in this study that we are at a point in definition of a facility which is equivalent to the conceptual phase of a major systems acquisition cycle. In this conceptual phase, we are defining operational and functional requirements at a high level. A realization of these requirements in terms of hardware is well into the future. This situation, however, is not as "clean" as that since there are equipments in existance which perform the desired functions. These known items are presented as alternatives and could be scored at an interval or ratio scale level in many criteria based on their respective developmental and operational test (DT/OT) results. The problem is that there are other alternatives--equipment mixtures, new start--whose characteristics are not as well known.

In order to compare all alternatives fairly, we find that digression to an ordinal scale of measurement provides the necessary level of comparability. This causes no hardship in subsequent analysis for there are a multitude of procedures in both decision theory and non-parametric statistics which are applicable. Underlying all of this is the assumption that in the case of modification of existing equipment or design and purchase of a new item, we will get exactly what we specify. That is, if we assign values to a new start so that it ranks higher than any existing or planned item, then we assume that we will specify, design and procure that item with the exact qualities which caused it to score higher. The decisions which are made may be wholly dependent on this single assumption, or they may be completely insensitive. The point is, we do not know at this point, so we must attempt to keep as much generality as possible in the decision process. The perceived good intentions of using interval or ratio scales at this point in the conceptual phase would require highly premature estimates of the qualities of our desired modification or new start equipment.

The ordinal scales and values which will be used in this application are:

Poor, fair, average, good, and excellent (1, 2, 3, 4, and 5 respectively).

Mission essential, minimum enhancement above mission essential capability, nominal enhancement, and maximum enhancement <0>, <1>, <2>, and <3> respectively.

Low, below average, average, above average, high (5, 4, 3, 2, and 1 respectively).

The adopted standard for this study is that larger values are better, smaller values are worse. This is usually quite obviously related to the criteria except in cases where "lower is better." When considering criteria such as cost or complexity, it is easy to see that a larger value is desireable, meaning lower cost or less complexity, respectively.

3. Why Other Decision Techniques Do Not Apply

There are numerous objective, seemingly straightforward, single and multiple criteria decision techniques for comparison and selection between alternatives. When these are examined closely, we find that many assumptions are necessary to construct the so-called objective viewpoint prior to subsequent analysis and decision. In the acquisition of military systems, it is typical to find these assumptions used to construct various measures of effectiveness (MOE's) so that competing systems can be compared in cost and operational effectiveness analysis (COEA) studies. Underlying these measures of effectiveness are the falacies of the process. When the envisioned item or system is in the early stages of development, and we have very little empirical data to support inferences about its quantifiable inherent input and/or output characteristics, we must make predictions or assumptions of factors such as: cost, risk, numerous "-ilities", performance, etc. In some cases, factors or criteria are too abstract to be clearly quantifiable (e.g.: What is a unit of performance?; risk?). Our premature search for definition often leads us to formulate models and draw inferences and conclusions which can be quite divergent from the eventual reality. Some of the more common quantitative decision making techniques are outlined below with comments on their shortcomings and lack of applicability in this particular situation.

One of the most often used and abused measures is expected value. It is easy to understand and calculate. Most decision makers are not aware of, or will overlook the fact that the basis for expected value holds only for a large number of trials and its use for one-time decisions is not appropriate. In a military setting, this abuse of expected value is most apparent in our use of point estimates such as mean time between failure (MTBF), and other derived quantities, with their inherent biases and variances, as underlying assumptions in the evaluation of a system. We often base these estimates on the field test performance of development models which are often not representative of the ultimately fielded equipment. If we then model a series/parallel system using these same expected value estimates for each component, the error variance is compounded, often giving misleading results which we use in even higher level estimates and COEA studies.

If we have a single criterion or can reduce the problem to a single valued measure of effectiveness or figure of merit (FOM), then we can choose a matrix approach. Also needed are the probabilities for all future states of the system. In matrix form, the rows represent the alternative choices or systems; the columns represent the possible future states with their associated probabilities; and the matrix entries represent the MOE or FOM for the alternative in that future state. The MOE or FOM values are either known or obtained by calculation or estimation (perhaps with significant error--see above). The probabilities of each future state are occasionally known (not likely), estimated, assumed to be equally likely, or we can use the "most probable future" method. Once the matrix is completed by assignment of MOE/FOM values and probabilities, the alternative choice is reduced to the use of one of several techniques (expected value, Maxi-Min, Mini-Max, Min Regret, etc.), as appropriate, depending on the particular application. The subject application of this study is multi-criteria and because of the nature of these criteria, and the lack of properly scaled data, calculation of a single MOE/FOM is not appropriate.

If there are multiple criteria (dimensions) to be evaluated across the alternatives then a traditional approach would be to weight the criteria. Once weighted, the criteria can be aggregated to produce the desired MOE/FOM. Explicit weighting requires independent, ordered criteria and criteria that have compatible units. Neither condition is completly satisfied in this particular application. The criteria of this study are somewhat dependent (e.g.: cost and performance), and they are ordinally valued (no specific units). It is preferable to treat them as equivalent (unordered, indifferent) in 3 of the 4 approaches, invoking a weak, but unquantifiable, preference only when necessary. Additionally, explicit weighting is most often incapable of responding to the dynamics of a rapidly changing future state environment (e.g.: mission profiles, battle damage, etc.). Weights define the relative "worth" of an criteria in the presence of others which remain constant and are independent. When there is dependence, just as in multiple regression, varying one or more of the other variables almost always results in a change to the coefficient (weight) of the variable cf interest. Finally, if there is dominance of one alternative over another, there is no combination of explicit positive weights which can alter that dominance. The weights, therefore, are meaningless. It is certainly possible to develop a dynamic weighting scheme for the given criteria. Formulation of such a scheme would require extensive and accurate information on the behavior of each criterion for each specific alternative. This accurate information can be obtained by multivariate regression analysis of data provided by: collection of data from users, simulation and/or operational field testing; all of which require the dedication of resources to obtaining an estimate which may not be consistent nor independent of other criteria. This level of effort is not within the scope of this preliminary study. It would, however, be of interest to develop these weights in subsequent studies and/or theses.

4. Assignment of Values to the Alternatives

The scoring of the alternatives was accomplished by the author and was based on: personal knowledge of the equipment, and a review of relevant literature, technical manuals, and test reports. Each alternative was grouped and ranked by comparison with the others. The scoring was done independently on each different criteria as if it were the only measure being utilized.

a. Assigning Values to Near Term Alternative Vectors

The four criteria for evaluation of the near term alternatives are: timeliness/availability (T/A), analog performance (AP), digital performance (DP), and cost ($$). The classification and ranking of the near term alternatives is summarized in Table 2 below.

TABLE 2

ASSIGNMENT OF NEAR TERM VALUES

Criteria	Nom/Ord Scale	Alternative(s)
T/A	poor	12
	fair	1, 11
	average	7, 10
	good	4, 6, 8, 9
	excellent	2, 3, 5
AP	<0>	2, 3, 4
	<1>	
	<2>	5, 6, 7, 8, 9, 10
	<3>	1, 11, 12
DP	<0>	
	<1>	
	<2>	2, 3, 4, 5, 6, 7, 8, 9, 10
	<3>	1, 11, 12
$$	low	2, 3
	below average	4, 5
	average	6, 7
	above average	8, 9, 10
	high	1, 11, 12

The tabulated classifications and ranks of Table 2 result in the near term alternative vectors shown in Table 3 in the following section.

b. Assigning Values to Long Term Alternative Vectors

The ten criteria for evaluation of the long term alternatives are: digital performance (DP), analog performance (AP), manual back-up capability or "failsoft" (MBU), standard USMC/off-the-shelf (STD), interoperability (IOP), system complexity index (SCI), technological risk (TR), timeliness/availability (T/A), planned upgrade to all digital (PIP), and cost ($$). Due to the number of criteria for the long term classification and ranking procedure, the details of the process are shown in Appendix F with the results summarized in Table 3 below.

5. Summary of the Resulting Alternative Vectors

The resulting alternative vectors are summarized in Table 3 below. The reader is reminded that "bigger is better" and that the values shown are ordinal scale; they do not represent interval or ratio scale data.

TABLE 3

SUMMARY OF SCORED ALTERNATIVE VECTORS

Alt	Near-Term Vector	Long-Term Vector
1	(2,3,3,1)	(3,3,2,3,3,1,3,3,5,1)
2	(5,0,2,5)	(2,1,2,5,3,2,5,5,5,5)
3	(5,0,2,5)	(2,1,3,5,3,3,5,5,3,4)
4	(4,0,2,4)	(2,1,3,4,3,3,5,5,4,4)
5	(5,2,2,4)	(2,2,4,5,4,3,5,5,3,5)
6	(4,2,2,3)	(2,2,5,4,4,3,4,5,3,4)
7	(3,2,2,3)	(2,2,5,4,4,3,4,5,4,3)
8	(4,2,2,2)	(2,2,4,3,4,2,3,4,3,3)
9	(4,2,2,2)	(2,2,5,3,4,2,3,4,3,3)
10	(3,2,2,2)	(2,2,5,3,4,2,3,4,4,2)
11	(2,3,3,1)	(3,3,4,4,5,1,3,3,5,2)
12	(1,3,3,1)	(3,3,5,5,5,1,2,3,5,1)

C. APPLICATION OF DECISION THEORY

This study proposes to avoid most of the pitfalls of underlying assumptions, inappropriately weighted aggregation of multiple criteria, and abuse of expected value by using a subjective, ordinal valued ranking technique. The justification, in general, is that the discussed alternatives do exhibit a natural classification or ordering when viewed unidimensionally one criteria at a time. This qualitative ordering of the alternatives is based solely on subjective, rational human thought and is not quantifiable on an interval or ratio scale. These criteria will be treated as equivalent (lexicographic indifference among criteria) in all cases except the aspiration level analysis, where they will be lexicographically ordered with "weak preference" thus providing an orderly scheme of evaluation should relaxation of preferences be necessary. This approach provides a method for evaluation which is relatively free from the shortcomings of the so-called objective techniques.

There will be an examination of the alternatives for dominance, followed by the utilization of three multi-criteria decision techniques: aspiration with relaxation, multi-dimensional vector to scalar transformation, and an application of the non-parametric Mann-Whitney test. Dominance and aspiration with relaxation together are similar to what Coombs refers to as the conjunctive model [Ref. 24: pp. 254-259]. Both techniques are included since dominance alone does not produce an ordered solution. Aspiration with relaxation in addition to multi-dimensional vector to scalar transformation are from Easton [Ref. 25: pp. 188, 170-172 resp.], and the non-parametric pair-wise Mann-Whitney test is from Conover [Ref. 26: pp. 216-218].

The application of dominance should yield a reduced set of viable alternatives while each of the latter three techniques will result in a preferentially ordered set of optimal alternatives for both the near and long term solution. It is anticipated that an ordered intersection of these sets can be constructed and that it will be non-empty containing the "best" alternative solution(s). Under the assumption of equivalence the criteria, the vector to scalar transformation produces a quantity which could be utilized as an MOE or FOM. The dominated alternatives (if any) will be retained for the dimensional analysis and the Mann-Whitney tests as a means of validation of those particular decision processes. Recall that, following the complete process, an analysis of the effects of the resulting near term choice upon the long term alternatives will be assessed and reported. Additional details of the processes for both near term and long term can be found in Appendix F.

1. Dominance

Dominance is defined as being less preferred or equivalent, on all criteria, to another alternative. If there any alternatives which are clearly dominated, then they are eliminated to reduce the range of choices. If there are any alternatives which are equal on all criteria, these ties will be retained as a means of validation in the subsequent decision process.

In the near term portion of the decision process there are two cases of tied alternatives: 1 is tied with 11 and 2 is tied with 3, and there are several cases of dominance: alternatives 1 and 11 dominate 12; alternatives 2 and 3 dominate 4; and alternative 5 dominates 6, 7, 8, 9, and 10. The remaining near term decision alternatives are: 1 and 11:(2,3,3,1), 2 and 3:(5,0,2,5), and 5:(5,2,2,4).

In the long term portion of the decision process there are no ties and several cases of dominance: alternative 5 dominates 3 and 8; alternative 6 dominates 9; alternative 7 dominates 10; and alternative 11 dominates 1. The remaining long term decision alternatives are: 2, 4-7, 11, and 12 as shown in Table 3 above.

2. Selection Based on Aspiration Levels

This method is essentially an application of Coombs' conjunctive model [Ref. 24: pp. 254-259] but can also be likened to a modification of Easton's "Combination Go, No-Go, Optimization Rule" [Ref. 25: p. 188]. It consists of selection of the alternative(s) which meet or exceed ("=>") a desired aspiration level vector across all dimensions or criteria.

a. Definition of the Aspiration Rejection and Acceptance Sets

The aspiration vector elements each define a plane in a space of the same dimension as the alternative vector. This space, inclusive of the boundary surface but not the "corner" points, forms the primary rejection space. Alternative points which are contained within the primary rejection space are currently in the rejection set but remain future candidates for membership in the acceptance set. The acceptance set is defined as the set of all alternative points which have been corner points of the primary rejection space. Points which lie outside the rejection space (none initially) are permanently rejected.

b. Initial Conditions

All alternative points which initially lie within, or on the surface of the contained space (but not on a "corner") are considered rejected. Corner points are accepted and gain immediate membership in the acceptance set. There will initially be no points outside the rejection space. When the aspiration level is set to the "best" in all criteria a maximal rejection space is defined. It would be highly unlikely for any alternative to qualify so relaxation (shrinkage) of the rejection space is required.

c. Successive Relaxation and Acceptance Requirements

For a point to enter the acceptance set as defined above, it must at one iteration in the relaxation process be at the intersection of all defined planes, that is at a "corner" of the space. This is found to be true since the space shrinks discretely and a weak preference relation is in effect along each dimension. This preference relation demands at least equality conditions on all dimensions (a "corner") before an alternative is accepted as preferred or indifferent to (">=") the successively relaxed aspiration space. The entire process, therefore, reduces to a simple check for equality between elements of the list of relaxed aspiration vectors and the remaining alternatives. If equality is found, that alternative enters the acceptance set. If the end of the relaxation is reached and some alternatives remain in the rejection set, then they are discarded as not acceptable.

d. The Actual Relaxation Process

Initially, the criteria are treated as equal or as if we were indifferent among them. Since no alternatives are acceptable, the criteria must now be viewed as "weakly" ordered (lexicographically: ">=" preferred or indifferent to) left to right,[12] we choose to selectively impose the weak "preferred to" condition as a means of sensitivity analysis. This enables a systematic relaxation of the threshold criteria, and consequently, reduction in the number of alternatives contained in the rejection set. If the values in the aspiration threshold vector are relaxed successively from right to left, one or more alternatives will eventually leave the rejection space through a corner point and will be accepted. This departure, as explained above, is simple equality with one of the successively relaxed aspiration vectors. Refer to Figure F.1 in Appendix F for a 3-space example of this relaxation process.

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[12] If the criteria are (j); j=1,2, ...,J; then this can be stated as: (1)>=(2), (2)>=(3), ..., (J-1)>=(J).

Let the initial threshold aspiration vectors for this application be as shown in Table 4 following. The range entries <a,b> define the maximum and minimum limits along a dimension of the rejection space. They are interpreted as meaning that the range of acceptable ordinal values for that criterion attribute is "a" to "b" inclusive. An "X" represents a don't care. The aspirations in this case would include the entire range of ordinal values. Rather than enumerate all of the additional relaxed aspiration vectors, the "X"-don't care is used to mean take the best value available of this criteria when the alternative meets all of the other threshold levels. The supporting detail for the initial long term aspiration vector is shown in Appendix F.

Since none of the candidate alternative vectors qualify under the constraints of the initial aspiration vectors (near and long term), relaxation is required. Successive relaxations of the initial near term vector and the points at which alternatives enter the solution set is as shown in Table 5 below.

TABLE 4

INITIAL ASPIRATION LEVEL THRESHOLD VECTORS

Near Term Aspiration

(<4,5>, <2,3>, <1,3>, X)

T/A	<good,excellent>	<4,5>
AP	<nominal,max>	<2,3>
DP	<minimal,max>	<1,3>
$$	"Don't Care"	X

Summary Long Term Aspiration

(<2,3>,<1,3>,<4,5>,<4,5>,<4,5>,X,<3,5>,<3,5>,<4,5>,X)

TABLE 5

SUCCESSIVELY RELAXED NEAR TERM ASPIRATION VECTORS

0	(5,3,3,X)	
1	(5,3,2,X)	
2	(5,3,1,X)	
3	(5,2,3,X)	
4	(5,2,2,X)	= Alt. 5 enters
5	(5,2,1,X)	
6	(4,3,3,X)	
7	(4,3,2,X)	
8	(4,3,1,X)	
9	(4,2,3,X)	
10	(4,2,2,X)	= Alts. 6 > 8, 9 enter
11	(4,2,1,X)	

There are 864 iterations in the successive relaxation of the long term aspiration vector, they will not be shown here. Table 6 below illustrates only those vicinities where significant events are occurring as indicated by the entry of the various alternatives into the acceptance set.

TABLE 6

SUCCESSIVELY RELAXED LONG TERM ASPIRATION VECTORS

000	(3,3,5,5,5,X,5,5,5,X)	
001	(3,3,5,5,5,X,5,5,4,X)	
002	(3,3,5,5,5,X,5,4,5,X)	
	...	
	(3,3,4,4,5,X,3,4,4,X)	
---	(3,3,4,4,5,X,3,3,5,X)	= Alt. 11 enters
	(3,3,4,4,5,X,3,3,4,X)	
	...	
	(2,2,5,4,4,X,4,5,5,X)	
---	(2,2,5,4,4,X,4,5,4,X)	= Alt. 7 enters
	(2,2,5,4,4,X,4,4,5,X)	
	...	
863	(2,1,4,4,4,X,3,3,4,X)	

The comparison of the several iterations of relaxed aspiration vectors (Tables 5 and 6 for near and long term resp.) with the alternatives vectors in Table 3 above leads to the selection of alternatives "5", "6", and "8/9" as viable for the near term and alternatives "11" and "7" as viable for the long term. The ordering left to right indicates their order of preference within their respective acceptance sets.

3. Ordinal to Utility Value Conversion

The remaining two techniques require that the criteria values be on the same scale. The simplest method to accomplish this is to convert each attribute's range of values to a equivalent 0-100 utility scale using a positive linear utility curve transformation. It must be noted that not all of the chosen criteria are most accurately represented by a linear utility function but it was chosen for simplicity and in the absence of additional data to support another, more accurate, choice of utility curve.[13] The ordinal ranges, their initial values, and their positive linear adjusted utilities are shown in Table 7 below. The converted near and long term alternative vectors are summarized in Table 8 and note that the alternatives which were dominated earlier (marked with "*") have been retained as a means for validation of the following two decision techniques.

4. Selection Based on Dimensional Analysis

The following dimensional analysis or vector to scalar conversion assumes equivalence of the dimensions (criteria) [Ref. 25: pp. 170-172].

a. Alternative J-Space Defined

Since the alternative vectors are j-dimensional (j=4 or 10, for near and long term, resp.), let us define a j-space where the origin can be viewed as the worst possible alternative (e.g.: zero capability). In this space, there is an axis for each of the multiple criteria. Each alternative criteria represents the value for a projection of the alternative vector on that criterion axis in the j-space. As we move away from the worst possible alternative, the origin, in any single dimension (e.g.: digital performance, cost, ...) we are improving

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[13] See Easton [Ref. 25: pp. 148-150] for an excellent description of several of the more common of these utility curves. Also refer to Appendix F for a brief discussion and figures of the simpler utility curves.

TABLE 7
ADJUSTMENT FROM ORDINAL TO UTILITY VALUES

Range	Values	Utility Values
poor	1	0
fair	2	25
average	3	50
good	4	75
excellent	5	100
high	1	0
above average	2	25
average	3	50
below average	4	75
low	5	100
<0>	0	0
<1>	1	33
<2>	2	67
<3>	3	100

our posture since each attribute of the alternative vectors represents a "bigger is better" score. Figure F.3 in Appendix F shows this structure for an example in 3-space.

By a j-space extension of 2 and 3-space properties, a point more distant from the origin in this j-space is ranked "better" across all equivalent dimensions or criteria (e.g.: a nearer to optimal mix of rankings).

b. Problems with Ties and Inconsistencies

There are problems with this technique, however, since there is the possibility of a tie or an inconsistency. The criteria are not weighted, yet they can be ranked by preference, so that ties can be resolved by invoking the "weak" preference aspect of the ">=" ordering of the criteria and by examination and selection of the alternative which first contains a higher criteria ranking, moving in

TABLE 8

ADJUSTED ORDINAL TO UTILITY VALUED ALTERNATIVES

Alt	Near-Term Vectors
1	(25,100,100,25)
2	(100,0,67,100)
3	(100,0,67,100)
4	(75,0,67,75) *
5	(100,67,67,75)
6	(75,67,67,50) *
7	(50,67,67,50) *
8	(75,67,67,25) *
9	(75,67,67,25) *
10	(50,67,670,25) *
11	(25,100,100,0)
12	(0,100,100,0) *

Alt	Long-Term Vectors
1	(100,100,25,50,50,0,50,50,100,0) *
2	(67,33,25,100,50,25,100,100,100,100)
3	(67,33,50,100,50,50,100,100,50,75) *
4	(67,33,50,75,50,50,100,100,75,75)
5	(67,67,75,100,75,50,100,100,50,100)
6	(67,67,100,75,75,50,75,100,50,75)
7	(67,67,100,75,75,50,75,100,75,50)
8	(67,67,75,50,75,25,50,75,50,50) *
9	(67,67,100,50,75,25,50,75,50,50) *
10	(67,67,100,50,75,25,50,75,75,25) *
11	(100,100,75,75,100,0,50,50,100,25)
12	(100,100,100,100,100,0,100,50,100,0)

* Previously dominated alternatives.

step-wise fashion, from left to right. This is valid as long as the criteria are at least weakly ordered.

Inconsistencies refer to the situation where an alternative ranked lower for smaller values of (j) yet ranked larger for higher values of (j) has a computationally greater length than a vector ranked in a manner closer to a monotonically non-increasing function for increasing values of (j).[14] These inconsistencies can be detected by observation or by noting disagreement with the results of the other techniques and will be resolved on a case by case basis by: examination of the variance of the competing rankings and/or by using only the most significant (leftmost) criteria rankings as "tie-breakers."

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[14] An example would be A(1)=(3,2,2) versus A(2)=(2,3,3).

c. Vector to Scalar Computation and Results

The most distant point from the origin in the defined j-space is determined by calculation of the lengths of all alternative vectors using the standard Euclidean norm:

$$D_i = \left(\sum_{j=1}^{J} a_{i,j}^2 \right)^{1/2}$$

where: J 4, 10 for near, long term resp.

$a_{i,j}$ the elements of alternative vector A_i

The results for the set of alternatives are essentially unweighted figures of merit (FOM) and are shown in Table 9 below.

Alternatives "2/3" and "8/9" for the near term are tied as they should be (earlier result) so all are retained in the solution set. There are apparent inconsistencies in the near term. Alternatives "11" and "12" score better than "6" but the latter scores better in the leftmost criteria and has less variance than "11" and "12" (83.19 versus 1992.19 and 2500 resp.). Consequently, alternative "6" is actually preferred over "11" and "12". There was one tie in the long term between alternatives "6" and "7" but it was resolved by examination of Table 3 above. They are tied in all criteria 1-8, but since alternative

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The lengths are 4.12 and 4.69 respectively yet alternative A(1) seems the most desireable since it is ranked higher than A(2) in the "weakly" preferred leftmost criteria.

TABLE 9

FIGURES OF MERIT - RESULTS OF DIMENSIONAL ANALYSIS

Alt	Near-Term Length	Long-Term Length
1	145.77	(201.56)*
2	156.49	243.57
3	156.49	(226.28)*
4	(125.46)*	223.50
5	156.85	255.40
6	(130.78)*	237.65
7	(118.23)*	237.65
8	(123.40)*	(190.99)*
9	(123.40)*	(202.12)*
10	(110.01)*	(205.19)*
11	143.61	238.48
12	(141.42)*	269.26

* Previously dominated alternatives.

"7" is ranked higher in criteria 9 (PIP), it is therefore preferred to "6".

The application of this technique leads to the selection of alternatives "5", "2/3", "1", and "6" as viable for the near term and alternatives "12", "5", "2", "11", "7", and "6" as viable for the long term. The ordering left to right indicates their order of preference within their respective sets.

5. Selection Based on Pair-Wise Mann-Whitney Test

In this final application, also using the converted utility valued alternative vectors, a comparison is made between each pair of alternatives to determine if there is an indication of preference, and in which direction. We assume that each alternative vector represents the mean response from a population of equipment identical to that described in the discussion of the alternative. That is, the vector summarizes the characteristics of that alternative population along the several criteria dimensions but is not a random sample. These alternative vectors were created by a scoring process, not a sampling process.

The Mann-Whitney test, as outlined in Conover [Ref. 26: pp. 216-218], is normally constructed as a test of hypotheses. That is not the case in this application. Since the Mann-Whitney assumptions are not met: the vectors are not random samples, and there is a lack of independence between alternatives, and between criteria[15] the procedure is applied only to calculate a preference measurement value. This value, or Mann-Whitney test statistic, is indicative of a directional trend (when not = 0) or indifference (when = 0) in the preference of one alternative A(i) over another A(j). It must be noted that values near zero may be due to random effects and not be indicative of any trend whatsoever. For the purpose of this study, if a non-zero value results, then a direction is inferred and the appropriate (weak) preference is reported. This information will be utilized to group alternatives, consolidate preferences and construct a logical ordering to the alternatives.

The detailed results of the Mann-Whitney calculations and anlysis are displayed in Appendix F. Shown below in Table 10 are the summary preferences for both the near and long term.

By counting the number of left-hand-side occurances of each alternative (i.e.: LHS > RHS) it is possible to rank them, breaking ties by examination of the tied alternatives for a preference among themselves. Additionally, it is

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[15] The alternatives which employ the AN/TTC-42 are not independent. The cost criteria is influenced by most others.

TABLE 10
SUMMARY OF PAIR-WISE MANN-WHITNEY RESULTS

Near Term Preferences

1>4
1>8
1>9
1>10
1>11
1>12

2>4
2>6
2>7
2>8
2>9
2>10
2>11
2>12

3>4
3>6
3>7
3>8
3>9
3>10
3>11
3>12

4>6
4>7
4>8
4>9
4>10

5>1
5>4
5>6
5>7
5>8
5>9
5>10
5>11
5>12

6>7
6>8
6>9
6>10

7>10

8>7
8>10

9>7
9>10

11>4
11>8
11>9
11>12

12>4

Long Term Preferences

2>1
2>3
2>4
2>8
2>9
2>10
2>11

3>1
3>8
3>9
3>10

4>1
4>3
4>8
4>9
4>10

5>1
5>2
5>3
5>4
5>6
5>7
5>8
5>9
5>10
5>11

6>1
6>2
6>3
6>4
6>8
6>9
6>10

7>1
7>2
7>3
7>4
7>8
7>9
7>10

8>1

9>1
9>8

10>1
10>8
10>9

11>1
11>3
11>4
11>8
11>9

12>1
12>2
12>3
12>4
12>5
12>6
12>7
12>8
12>9
12>10
12>11

necessary to examine closely related scores (+/-2) to determine if there are any inferences of overriding preferences to be resolved. It is concluded from this summary that: "5" is preferred to "2/3" > "1" > "11" > "4" for the near term. Note that "11" scores lower but was given explicit preference over "4". The long term result is "12" preferred to "5" > "7/6" > "2" > "11". Note that the tie between "6" and "7" was again resolved as earlier.

D. SUMMARY OF ALTERNATIVE SELECTION PROCESS

The results of the above multi-criteria decision decision making techniques are shown in Table 11 below. The parenthesized lists in the top half of Table 11 are the sets of alternatives which were identified as "best/better" at each step in the process. Within each set except dominance, the alternatives are preferentially ordered (e.g.: a > b > c ...) from left to right. The dominance result is not preferentially ordered but simply contains the dominant alternatives in numerical sequence.

The ordered "intersection" at the center of Table 11 was formulated by a scoring tabulation of the various alternatives and their orderings in the prior solution sets. Table 12 shows all near term alternatives (rows) scored by the number of times they finished first, second, ..., (cols) in the three ordered solution sets (aspiration, dimensional, and Mann-Whitney). Analysis of Table 12 leads to the conclusion that a reasonable near term intersection should consist of: "5" > "2/3" > "6" since their scores indicate that particular ordering. Table 13 shows the scoring summary which is used to construct the long term ordered intersection of: 12 > 11 > 5 > 7 > 6/2. An apparent inconsistency, in terms of capability, between "2" and "6" is resolved by noting that "6" ranks better than "2" in the leftmost criteria.

The bottom of Table 11 summarizes the result of taking the ordered intersections in combination with the effect of long term dependence upon the near term selection(s).

TABLE 11

SUMMARIZED RESULTS OF DECISION ANALYSIS

Method	Near-Term Result	Long-Term Result
Dominance:	(1,2,3,5,11)	(2,4,5,6,7,11,12)
Aspiration:	(5,6,8/9)	(11,7)
Dimensional:	(5,2/3,1,11,4)	(12,5,2,11,7,6)
Mann-Whitney:	(5,2/3,1,11,4)	(12,5,7/6,2,11)

Intersection: near term choices= (5,2/3,6)
long term choices= (12,11,5,7,6,2)

Near-Term	Long-Term Choices
If 5 then:	12,11,5,7,6
If 2/3 then:	12,11,5,7,6,2
If 6 then:	12, 11, 7

TABLE 12

COUNT OF NEAR TERM ALTERNATIVE ORDERS

	Score by Orderings				
Alts	1	2	3	4	5
1:			2		
2:		2			
3:		2			
4:					1
5:	3				
6:		1		1	
8:			1		
9:			1		
11:				1	

TABLE 13

COUNT OF LONG TERM ALTERNATIVE ORDERS

	Score by Orderings				
Alts	1	2	3	4	5
2:			1	1	
5:		2			
6:			1		1
7:		1	1		1
11:	1			1	1
12:	2				

Given that we will select from the near term alternative solution set, the effect on the long term decision can be assessed. The analysis considers the preference and capabilities of the remaining elements in the long term ordered "intersection" solution set after the establishment of the near term baseline selection and its capabilities.[16] It is assumed that we will not select a long term solution of lesser capability than the near term but one of greater or at least equivalent capability. Considering the results shown in Table 13 the analysis proceeds as follows:

1. If the most preferred alternative, "5", is selected in the near term, then, any choice from the long term intersection except "2" is acceptable. We would not consider any alternative of lesser capability for the long term, thus alternative "2" would be eliminated from the choices.

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[16] For example: if the choice for the near term were the AN/TTC-42 employed with the AN/TSQ-84 ("5") then, logically, the long term choices would not include applications of less capability than the established near term baseline; such as the TTC-42 and: no TCF ("2"), AMDF ("3"), etc., (refer to the alternatives listed in an earlier chapter).

2. If "2/3" is chosen in the near term, then the viable choices for the long term include all elements of the intersection.
3. If "6" is chosen, then the long term solution set includes all of the long term alternatives in the ordered intersection except "5" and "2" since they are both of lesser capability than "6".

VII. CONCLUSIONS AND RECOMMENDATIONS

This has been a preliminary study of the needs of the USMC for technical control in the near term (1987-1990) analog and digital environment and the long term (1991+) all digital envirionment. It has maintained a somewhat higher level of discussion than that necessary to actually define an equipment solution beyond the block diagram level. The approach has been similar to a systems engineering functional description process in the conceptual phase of a system acquisition cycle. The major difference between this approach and a completely new start concept is that there exist equipment solutions already in production and/or completing their design phases which are viable. These have been included as alternatives.

A. STUDY OBJECTIVES

The original request for study stated an overall objective of:

> "This study is to determine the digital technical control requirements, and discuss the modification or replacement of the AN/TSQ-84 to provide the necessary facilities in a digital communications environment. This will provide an essential element in assessing the impact of digital systems and digital data communications on the Landing Force Integrated Communication Systems (LFICS) architecture."

There were three specific objective inquiries. The study results for these three inquiries is presented in the following.

1. Applicable FMFM 10-1 Digital TECHCON Functions

Objective 1: "Determine which of the FMFM 10-1 TECHCON functions apply in a digital environment."

Conclusion 1: TCF Functions

There is no difference in the functions of an analog or digital technical control facility. The differences are found in the procedures and tasks which implement those functions. This misconception stems in part from the presentation in FMFM 10-1 (see Appendix A) which is a mixture of technical and management functions and procedures. The emphasis should specifically be on technical functions. Also, they are redundant and are not in consonance with technical control functions as defined by the other services and industry.

Recommendation 1: TCF Functions

It is recommended that the following widely accepted general functions be accepted as the required technical control functions, replacing those currently found in FMFM 10-1.

"The LFICS technical control facility must contain the resources to provide the capability for network and nodal functions as appropriate for its level of command and control. These general functions are:

- Circuit Connectivity,
- Circuit Monitoring, and Testing,
- Fault Isolation,

- Circuit Restoral, and
- Circuit Status Reporting."

These functions are applicable for analog, analog/ digital, and all digital systems. The differences will occur in the procedures and tasks mentioned in the next objective.

2. Implementation of TECHCON Functions

Objective 2: "Identify implementation methods for these digital TECHCON functions."

Conclusion 2: TCF Procedures and Tasks

It is necessary to separate the functions from the procedures and tasks which are performed in their implementation. Viewing the above stated functions now from a procedural side, the outline below is provided as a starting point for future consideration and further development.

Recommendation 2: TCF Procedures and Tasks

It is recommended that the following be included in the FMFM 10-1 as a basic listing of technical control analog and digital procedures and tasks:

"The technical control facility will implement its functions in the following general manner as appropriate for its level of nodal services to command and control elements:

a. Circuit Connectivity

The technical control facility will provide, as a minimum, physical connectivity between all nodal communications center, tactical data system, and subscriber equipment; switching equipment; and transmission media. This connectivity will be used to install, activate, re-route, and deactivate nodal circuits as directed by the OSCC. Above the basic physical level, connectivity implies circuit signal compatibility. This compatible interface will be achieved by the use of digital group modems, time division multiplexing equipment, bulk encryption devices, buffering equipment, net radio interface devices, etc. The requirement for a compatible interface also implies the application of analog and digital circuit line conditioning equipment such as: line amplifiers, attenuators, delay line equalizers, delay envelope equalizers, etc. At higher echelons (MAF, MARDIV, ...) this connectivity may be implemented by use of an electronic switch matrix as part of the main distribution frame (MDF).

b. Circuit Monitoring

The technical control facility (TCF) will continuously supervise and monitor analog and digital circuit quality. It is equipped with a suite of manual, semi-automatic and/or automatic test, measurement and diagnostic equipment (TMDE) depending on its location. These items of TMDE will be constantly employed to monitor active circuits, on a non-interference basis ("in-service" test), to detect circuit degradation problems before they become or cause catastrophic failures. Some of the typical tests are: bit-error-rate test, bit count integrity, dropouts, impulse hits, phase jitter, signal to noise ratio, etc. If a circuit failure occurs, or a degraded condition is detected through monitoring, this same TMDE will be used to thoroughly test and evaluate the subject circuit. The testing results will be quantified and analyzed to determine the degree of circuit degradation and if restoral is achievable using line conditioning techniques.

c. Fault Isolation

When a circuit failure occurs, the cause will be isolated by the proper application of troubleshooting techniques. The remote ends will locally test there respective equipment, if appropriate. Simultaneously, the TCF will begin to verify the circuit in ever increasing distance from the main distribution frame. When the circuit degradation or failure is introduced, the problem will have been localized to the last included item of equipment and/or transmission media. This procedure is accomplished by the direction and control of PTF's, and dispatched troubleshooting teams. Isolation of a faulty component will often require the application of previously mentioned test and monitoring procedures on the "out of service" circuit.

d. Circuit Restoral

A degraded or failed circuit is restored by substitution of a spare equipment or media for the failed component, re-routing by changes in connectivity, application of line conditioning to correct an out of tolerance condition of one or more of the circuit properties, and/or actual on-line repair of the failed or degraded component. Following any restoral action, however minor, the TCF will verify that the restored circuit functions properly prior to its return to service.

e. Circuit Status Reporting

The technical control facilty will maintain circuit, status, and activity logs; routing and traffic diagrams, etc. in accordance with DCA standards and locally approved instructions. The reporting and coordination between the TCF, the local OSCC, and other senior, adjacent and subordinate TCF's will be accomplished through dedicated order-wire circuits using automatic (telemetry) or manual techniques.

B. SUMMARY STATEMENT OF THE NEED

Need 1: Near Term (1987-1990)

Determine what systems and/or equipments are required to meet the needs of near term hybrid analog/digital technical control in the LFICS.

Need 2: Long Term (1991+)

Determine what systems and/or equipments are required to meet the needs of long term all digital technical control in the LFICS.

The basic assumption throughout this study discussion was that the existing technical control facility, AN/TSQ-84, would either prove to be totally inadequate for the mission or it would be clearly inferior to other existing, developing or new start facilities. The following is a summary of the study findings relative to the needs and the applicability of the AN/TSQ-84 and other equipment alternatives.

C. APPLICABILITY OF THE AN/TSQ-84 FACILITY

Objective 3: "Determine to what extent the AN/TSQ-84 can accomodate the digital functions; and, if deficient in digital TECHCON functioning, determine modifications to the AN/TSQ-84 which would satisfy these requirements or identify alternative solutions."

A systems analysis approach was undertaken: introductory and background information was examined, the needs were identified (as above), alternative solutions were constructed, these alternatives were scored, and a decision process was employed. The result is a prescriptive solution to the requirement for an upgrading of LFICS technical control capabilities in both the near and long term.

Contrary to the basic assumption, the existing technical control facility, AN/TSQ-84, remains a highly effective TCF when employed in the performance of technical control procedures and tasks. It can provide continued level <2> analog services and also provide level <1> digital services[17] for those circuits which are compatible with 26-pair, WD-1/TT "Slash Wire", or WF-16/TT media (generically: "twisted pair"). This includes nearly all of our planned near and long term user terminal equipment. It was noted in earlier discussion that all transmission media are analog devices whether the data being transmitted is analog or digital. The required monitoring, test, measurement and conditioning of analog media remains within the capability of the AN/TSQ-84. Also mentioned earlier were digital circuit monitoring and test procedures using "eye patterns" [Ref. 21] which employ only an oscilloscope such as currently available in the AN/TSQ-84.

Conclusion 3: Applicability of the AN/TSQ-84

The AN/TSQ-84 can continue to provide complete manual or semi-automatic analog service (Level <2>), and limited manual digital service (Level <1>) for "twisted pair" circuits.

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[17] These levels of service are defined in the preface glossary and in detail in Chapter IV.

D. ALTERNATIVES TO THE AN/TSQ-84 FACILITY

Beyond these capabilities, the AN/TSQ-84 would require limited modifications. As discussed in Chapter IV, an initial step toward improvement of the AN/TSQ-84 would be the AN/TSQ-84(M1). The "-84(M1)" would have interface modifications (internal or external) to allow connectivity of coaxial and fiber optic cable systems (most important for connection to the AN/TTC-42 and other TDM systems). An additional improvenment, the "-84(M2)" would include digital monitor, test, measurement and diagnostic equipment for application on the digital data circuits as well as the existing analog capabilities. At this final stage, the AN/TSQ-84(M2) becomes a viable alternative in the absence of other solutions. However, none of these solutions, the AN/TSQ-84, M1, or M2, provide the required encryption, multiplexing, buffering, etc., that is required of a full capability, central technical control facility.

There are existing or planned alternatives to the AN/TSQ-84 variety which are in production and/or in the design phase. Additional detail on these other service solutions to digital technical control in provided in Chapter V, and in Appendix C. It was concluded in Chapter V that there were twelve alternative methods of meeting the needs of analog/digital and all digital technical control in the near and long term. These methods involve various mixtures of both equipment[18] and capabilities and are formulated as follows:

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[18] The AN/TTC-42 (Enhanced) is implicitly employed as switching equipment. When mentioned in an alternative, it is being employed also as a limited technical control facility. [Ref. 19]

- Alternative "1": AN/TTC-39A replaces the AN/TTC-42 & AN/TSQ-84 (Fig. D.4).
- Alternative "2": AN/TTC-42 (Enhanced) replaces the AN/TSQ-84 (Fig. D.4).
- Alternative "3": AN/TTC-42 (Enhanced) and an analog MDF (Fig. D.5).
- Alternative "4": AN/TTC-42 (Enhanced) and a hybrid analog/digital MDF (Fig. D.5).
- Alternative "5": AN/TTC-42 (Enhanced) and AN/TSQ-84 (Fig. D.6).
- Alternative "6": AN/TTC-42 (Enhanced) and AN/TSQ-84(M1) (Fig. D.6).
- Alternative "7": AN/TTC-42 (Enhanced) and AN/TSQ-84(M2) (Fig. D.6).
- Alternative "8": AN/TSQ-84A replaces the AN/TSQ-84 (Fig. D.6).
- Alternative "9": AN/TSQ-84A(M1) replaces the AN/TSQ-84 (Fig. D.6).
- Alternative "10": AN/TSQ-84A(M2) replaces the AN/TSQ-84 (Fig. D.6).
- Alternative "11": AN/TSQ-111 replaces the AN/TSQ-84 (Fig. D.7).
- Alternative "12": AN/TSQ-xxx replaces the AN/TSQ-84 (Fig. D.7).

E. CONCLUSIONS AND RECOMMENDATIONS FOR THE NEAR AND LONG TERM

The above alternatives were scored (ranked) along several criteria which were developed and related to both the near and long term situations. Applications of multi-criteria decision theory and non-parametric statistics were utilized to construct several ordered solution sets. The conclusions drawn from the analytical intersection of these results clearly indicate the preferential ordering of choices as stated in the following recommendations:

1. Near Term Recommendation

The results of the decision analysis show that the best choice for the near term (1987-1990) is to employ the AN/TTC-42 (Enhanced) together with the AN/TSQ-84 (Alternative "5").

A second choice is either to utilize the TTC-42 alone as a combined switching/technical control facility (Alternative "2") or to use it together with an analog MDF (Alternative "3"). This either/or situation results from an exact tie in one of the four decision techniques.

A third choice is to employ the TTC-42 with the modified AN/TSQ-84(M1) (Alternative "6").

Conclusion 3: Near Term (1987-1990)

The above discussion of near term alternative choices restated simply in terms of preferential ordering is:

(AN/TTC-42 and AN/TSQ-84) > AN/TTC-42 or (AN/TTC-42 and AMDF) > (AN/TTC-42 and AN/TSQ-84(M1))

Recommendation 3: Near Term (1987-1990)

Employ the AN/TTC-42 as a combined SW/MPLX/TCF for most digital circuits together with the AN/TSQ-84 as the TCF for all analog and few digital circuits (Alternative "5").

2. Long Term Recommendation

The selection of the long term technical control facility is dependent on the near term choice. Since the recommended course of action for the near term is to implement the AN/TTC-42 with the AN/TSQ-84 (Alternative "5"), the alternative choices for the long term are: 12 > 11 > 5 > 7 > 6 (see alternatives listed above). Alternative "2" was also in the long term ordered solution set but it is of lesser capability than "5" so it is eliminated from consideration.

Conclusion 4: Long Term (1991+)

Considering the above discussion of the effects of dependency, and using only the three most preferred alternatives, the long term choices are restated in terms of preferential ordering as:

AN/TSQ-xxx > AN/TSQ-111 > (AN/TTC-42 and AN/TSQ-84)

Recommendation 4: Long Term (1991+)

Develop the "new start" facility, AN/TSQ-xxx (Alternative "12") for use in the long term.

F. APPLICATION OF DECISION THEORY IN SYSTEMS ACQUISITION

This study presented several alternative solutions to the near term problem of hybrid analog/digital and long term all digital technical control. Then, through an application of multi-criteria decision theory and non-parametric statistics, developed an orderly choice from among these alternatives. This process was relatively free from the typical underlying estimates used in cost and operational effectiveness analysis (COEA) type studies which are designed to compare and select from among competing systems. In the opinion of the author, the general application of the decision techniques outlined in this study are more appropriate than a COEA. This is especially true during the earlier systems engineering functional description phases in the conceptual stage of the system acquisition process. If we implement these decision theory techniques in parallel with existing procedures and evaluate their performance in actual systems acquisition, it is likely that the stability and robustness of the qualitative multi-criteria decision theory approach would be proven.

Hypothesis 1: Decision Theory vs. COEA

It is hypothesized that the decisions made with the techniques described in this study are as good and equally consistent over time as the more rigorous results from studies involving COEA's and other strictly quantitative techniques. If this hypothesis is accepted, these more qualitative techniques would be preferred as they require less "up front" quantitative estimation and aggregation than the other techniques.

Recommendation 5: Decision Theory vs. COEA

It is recommended that the Marine Corps adopt an interim policy of concurrent use of general qualitative multi-criteria decision theory in the earlier, systems engineering and conceptual stages of the system acquisition process. Then, if appropriate, following a suitable period of comparative analysis, substitute the exclusive use of these qualitative techniques.

APPENDIX A

COMMUNICATIONS CONTROL FUNCTIONS AND TERMINOLOGY

1. USMC - FMFM 10-1

System Control (SYSCON)

System Control (SYSCON) is a method of managing communication resources for the effective and economical utilization of personnel and equipment. It includes the continuous planning, engineering, determining of requirements, restoration policies, and centralized direction necessary to attain and operate a responsive telecommunication system. SYSCON is subdivided into the two functional areas of system planning and engineering (SPE) and operational system control (OSC).

System Planning and Engineering Element (SPE)

System planning and engineering is a function of the CEO's office. This function plans for the communication system by determining the number of circuits needed; determining circuit routes; and designing switching and OSC centers, technical, and other facilities as appropriate. Engineering is required to perfect these plans by precise determination of quality and quantity and determining specific utilization of equipment. The SPE emphasis is primarily directed toward the non-Defense Communication System (DCS) circuits of the command, but assistance may be required in providing detailed information to the regional Defense Communication Agency (DCA) organization for those DCS circuits which support the command. The major functional responsibilities of the SPE are:

The preparation and dissemination of general policies of the commander for the operation and usage of communications within his command.

The preparation and issuing of detailed instructions for usage of communications systems and equipment within the command and by subordinate units.

Maintaining continuous contact and liaison with other elements of the commander's staff to assure complete awareness of the continuously evolving plan of operation and the resulting communication requirements and the coordination with the communication staffs of friendly and allied forces in the tactical area of responsibility.

Planning and engineering the overall configuration of the command's communication network including the general locations of multichannel terminals, cable routes; points of interface with other systems; use of indigenous facilities; radio net structure, relay and retransmission sites; frequency requirements and allocations; and alternate means of communications such as motorcycle messengers.

The preparation and issuing of directives of the implementation of changes in network configuration, connectivity, or routing which may be neccessitated by unit displacement, modifications of unit missions, unsatisfactory system performance, or other reasons.

The continuous review of system status and of the performance of communication equipment and personnel.

The preparation and updating of contingency plans.

Maintaining the data-base information for SPE.

The preparation of reports on communication operations and maintenance of historical data and files.

Informing the commander and his staff of the communication situation.

Operational System Control (OSC)

The principal function of OSC is to ensure that all available circuits are used to the best advantage to fulfill the requirements of dynamic communication systems. The OSC staff is responsible for the day-to-day operation of the system and compilation of statisticsand reports for use in long-range planning. The staff will be the S-3 and his assistants in the communication unit, as appropriate. The major functional responsibilities of the OSC are:

The preparation and issuing of detailed directives and instructions to subordinate communication units for the implementation of communication plans and the supervision of their execution.

The monitoring of system performance and coordination of actions required for restoration of system outages, including coordination with senior, subordinate, and adjacent operational system control centers (OSCC's) as applicable.

The collection and analysis of traffic data, service complaints, and outage reports to identify and correct system inadequacies, procedural deficiencies, and other sources of problems, and to provide SPE with these analyses.

The preparation and distribution of information essential to the use and/or operation of the system, including directories, call signs, etc.

Maintaining system records and historical data, and rendering reports as required.

Making recommendations to SPE for corrective actions when the resources available to OSC are insufficient to provide satisfactory communication service.

The direction, via the OSCC, of the local technical control facility (TECHCONFAC) and the receipt of circuit information from the TECHCONFAC.

Operational System Control Center (OSCC) The OSCC is the activity, subordinate to the OSC staff, which maintains current information on the availability and operational readiness of communication resources. It controls, within prescribed parameters, the utilization of these resources to ensure maximum communication support to authorized users in accordance with established priorities. In controlling communication system operations, it gathers data required for management and control decisions. The OSCC is under the cognizance of the communications-electronics officer. The major functions of the OSCC are:

Implement and control the entire telecommunication system as one cohesive yet flexible entity.

Maintain current status of all circuits.

Provide reliable communication support for the command.

Supervise and make emergency adjustments to the existing communication system and act as a point of contact for the installation and maintenance of all transmission and terminal means and electrical power sources related to the circuits controlled by its facility.

Maintain data and records of the communication system.

Technical Control (TECHCON)

Technical control is the means of exercising centralized technical supervision over the installation, operation and maintenance of selected semipermanent circuits employed by organic and communication agencies and by other authorized subscribers. It provides for common interface between a medium and a user and between media.

The technical control facility (TECHCONFAC or TCF) is the agency established by organizatins that require a means for exercising centralized technical supervision over the installation, operation and maintenance of selected circuits employed by organic command, control and communications agencies; terminal equipment; and dedicated subscribers. It is the common facility which provides for interface between the terminal means employed by these users and the means providing the required signal paths to distant locations. A TECHCONFAC may be organized along functional lines to provide for continuity in its operation. It operates under the cognizance of the CEO/COMMO, supported by an appropriate number of watch sections.

The scope of a TECHCONFAC's operation is generally governed by the number and type of control and communication agencies, and other authorized subscribers which rely on this facility for the performance of selected circuits. Initially, The TECHCONFAC will operate to assist the implementation of the communication plan. Additionally, its operation will be influenced by the immediate technical arrangement of its facility and the wire and radio means available to provide the required signal paths. The majority of its functions require that it have some means for gaining access to the circuits that pass through the facility. Depending on the level of operation and the type of supervision required, a technical control facility may employ equipment associated with manual techniques or complex machine-oriented devices which provide for monitoring, performance testing, signal conditioning, circuit rerouting, and similar services. The effectiveness of a technical control facility may be measured by its ability to provide circuits of good quality, and to limit degradation of those circuits due to manmade or natural causes. The following functions do not elaborate on the numerous detailed procedures required for centralized supervision over the operation and maintenance of selected semipermanent circuits. They are presented to emphasize principles and techniques for effective operations and may be modified to satisfy local requirements. The major functional responsibilities of a TECHCONFAC are:[19]

Supervise analog and digital transmission circuit quality. (Monitoring)

Coordinate with senior, subordinate and adjacent technical control facilities in the exercise of technical supervision and control over common internodal circuits. (All)

Coordinate, supervise and control the employment of trouble teams. (Isolation, Restoral)

Provide for the activation and deactivation of circuits as directed by the local SYSCON (OSCC). (Connectivity)

Analyze (quantitatively) all properties and impairments involved in circuit interruptions, or disturbances due to manmade or natural causes. (Monitoring, Isolation)

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[19] These functions are extracted from FMFM 10-1, pp. 3-16 & 3-17. The are amplified and categorized by the 5 general functional areas of Table 1 in anticipation of their application to the discussion of LFICS in the main text of this study.

Direct the use of appropriate troubleshooting procedures, within the primary TCF, and through remote locations, to detect and isolate faulty terminal equipment (DTE), communications equipment (DCE), and circuit signal media. (Isolation)

Substitute equipment by patching, re-connection or appropriate coordination with remote communications facilities as directed by the operational system control center (OSCC). (Restoral)

Maintain the capability to establish alternate signal paths when primary paths are disrupted. (Connectivity, Restoral)

Maintain files and circuit logs in accordance with Defense Communications Agency (DCA) regulations and applicable local instructions. (Reporting)

Maintain circuit and traffic diagrams in accordance with Defense Communications Agency (DCA) regulations and applicable local instructions. (Reporting)

Maintain liaison with control and communication agencies (radio terminals; switching and communication centers) and other authorized terminal subscribers pertaining to the performance of nodal and network circuits and equipment. (Monitoring)

Ensure compliance with restoration priorities in accordance with Defense Communications Agency (DCA) regulations and applicable local instructions. (Restoral)

Maintain liaison with the OSCC pertaining to the availability and status of all circuits serving the node. This requires timely reporting of outages and progress of restoration efforts. (Monitoring, Restoral, and Reporting)

2. USA - FM 24-22 (Joint Terminology for JTC3A Systems)

This information is extracted from FM 24-22 [**Ref. 27: Chapters 2 and 7**]. It is provided to relate the common usage USMC communication control terminology to the newer, joint service terminology. The summarized functions of the various control elements are included for comparison with the above.

Communications System Planning Element (CSPE)

The CSPE is equivalent to the SPE above. The description of CSPE is:

Staff function.

Long range planning.

Detailed engineering.

Communications System Control Element (CSCE)

The CSCE is equivalent to the SYSCON (OSC) above. The CSCE is described as:

Dynamic control.

Realtime operations.

System focal point.

More specifically, the functions of CSCE are:

Implementation and installation. Prepares installation orders to subordinate elements (CNCE) which will implement CSPE planning/engineering action for: installation, restoration actions, and priorities; general site locations; radio antenna orientation; quantity and distribution of essential access and trunking circuits; modifications to communications links; interface facilities; switching, store and forward, and trunking equipment.

Monitoring. Maintains, analyzes, and displays system status information, including: traffic data; system and equipment performance data; equipment restoral status; grade of service; outages and backlog situations.

Traffic control management. Assures effective customer service through control measures such as: routing changes; truck barrings; line load controls (minimize); trunk and link directions; control of queues.

Transmission system routing control. Insures best use of resources through: reallocation of satellite and airborne rado relay channels; allocation of dedicated circuits; internodal routings; determination of number and distribution of trunking circuits; restoration priorities.

Reporting Assembles staff guidance for the commander.

Records keeping. Initiates, maintains, and retains the information which comprises the C-E data base.

Management of COMSEC resources including keying material.

Directory control. The updating and publication of directories, routing guides, etc.

Communications Nodal Control Element - Management (CNCE-M)

The CNCE-M is equivalent to the SYSCON (OSCC) above. The CNCE-M is the direct arm of the commander and replaces the facilities control function. The CNCE-M is primarily responsible for records and reports, accounting, coordination of communications requirements, and management of the communications equipment support elements (CESE's).

Communications Nodal Control Element - Technical (CNCE-T)

The CNCE-T is equivalent to the TECHCON above. The CNCE-T has direct control over circuitry and replaces the technical control function. It has all the required resources to perform technical supervision of communications media and equipment, to restore lost or degraded services, to accomplish continual quality assurance of installed circuitry, and to initiate new services on receipt of proper orders (TSO).[20] It also provides technical information to the CNCE-M for records and reports concerning installed circuits and systems.

For maximum efficiency, the CNCE-M and CNCE-T are co-located. When these elements are not co-located, the problems encountered in coordination, transfer of information, and response materially degrade the over-all C-E system.

Communications Nodal Control Element - General

The general functions of the combined CNCE are:

Management and technical direction. Exercises management and technical supervision over subordinate activities and CNCE's.

Implementation and execution. Responds to directives from the controlling CSCE.

Line circuit conditioning and interface with C-E systems. Provides equipment necessary to condition analog and digital circuits for best performance. Provides interface for direct current (dc) circuits, voice frequency circuits, dc-to-vf conversion, and anaolog to digital conversion, etc.

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[20] TSO - telecommunications service order.

Activation and deactivation of circuitry. Complies with CSCE orders. Directs subordinate activities and subscribers to execute orders. Coordinates with other CNCE's. MOnitors circuit activation and deactivation.

Technical coordination to accomplish quality assurance programs. Modifies or corrects circuit configuration and coordinates changes with CSCE. Tests installations of subordinate CESE's for adherence to established standards.

Maintenance of systems standards. Conducts in-service and out-of-service quality control through performance monitoring and testing. Conducts fault isolation on intranodal, internodal, and extension facilities (DCS, allied, commercial transmission systems). Refers fault isolation findings and corrective actions to appropriate subordinate activities.

Rerouting and restoration of circuits, groups, and systems; updates nodal records to reflect all changes.

Reports and reporting. Receives reports and takes the necessary action in the areas of activation and deactivation (TSO), resource commitments, trouble conditions, performance data, test results, and facility status. Sends reports to th econtrolling CSCE and to appropriate subordinate CESE's concerning activations and deactivations, trouble status, coordination with other CNCE-T's, equipment status, performance data, testing data, and system status.

Records keeping. Records are maintained for the current deployment as opposed to the comprehensive data base maintained by the CSCE. The records include:

Circuit records with orders and technical directives regarding circuit connectivity (TSO), electrical and physical connections at the CNCE nodal facilities for which it is technically responsible, and the availability of circuits at the node are necessary for real-time operation.

System and circuit status records of all systems and circuits terminating at the node.

Nodal data base update (directories, etc.)

Communications Electronics System Elements (CESE)

The CESE's are the hardware oriented operating elements of the communications system which have limited capability to detect, diagnose and fault isolate within their portion of the system. Some typical examples of CESE's are: multichannel radio terminals, circuit and message switches, etc.

3. USA - FM 11-486-19

The FM 11-486-19 [Ref. 28: pp. 5-20, 5-21] states, in general, that:

> ". . . control and management is provided through technical control facilities (TCFs) or patch and test facilities (PTFs) which offer the following five basic functions: patching, coordination, testing, monitoring, and reporting."

It further states that:

> "TCFs are placed where they can provide the greatest control over communications system operation; that is, switching centers, nodal points, etc."

This FM defines the general functions of technical control as:

Circuit performance status reporting.

Equipment performance status reporting.

System performance analysis.

Fault isolation, including analysis of trends.

Selection of alternative routes.

Circuit restoration.

Record keeping and reporting.

It also describes the functions of an automated technical control (ATEC) facility as:

Monitor critical equipment operations alarms which may be indications of conditions leading to catastrophic failures, such as power supply output voltage, loss of baseband pilots, transmission line deterioration, etc.

Perform in-service tests on a continuous basis while system is in operation and without disrupting service. Such tests include received signal levels, pilot tone levels and stability, transmitter output power, quality assurance (QA) monitoring, etc.

Perform out of service tests, which necessarily takes the system or parts of it out of regular service for the duration of the tests. Such tests includegroup/supergroup/baseband noise loading, link loop-backs, etc. However, many out of service tests--such as measurements of test tone level, idle channel noise, phase jitter, and frequency distortion--can be conducted using spare or idle channels. The imbedded ATEC computer can recognize and seize idle channels for this purpose.

Recognize, organize, record, analyze, and report test results.

Prepare required logs and reports.

APPENDIX B

A/D CIRCUIT PROPERTIES AND IMPAIRMENTS & LFICS SIGNALS

This appendix contains both a summary of analog/digital circuit properties and impairments, and of the LFICS equipment signal interface characteristics.

1. Analog/Digital Circuit Properties and Impairments

It is important to distinguish between the often confused terms: circuit properties and circuit impairments.

The properties of a circuit are constant characteristics. While they may be unique across circuits, they are essentially linear (e.g.: a function of distance travelled) and steady-state (not time dependent). The properties which are inherent in a circuit upon installation, accordingly, remain constant at all times. Some examples of circuit properties are: gain, amplitude distortion, delay distortion, and return loss. Because these properties are regular and predictable, they can be compensated for by the application of corrective measures, or "conditioning." Appropriate corrective measures for the above would be: attenuation, line equalization, delay equalization, and amplification (respectively).

Impairments fall within the general classifications of: hits, noise, jitter, and several types of distortion. Hits and noise are the most disruptive in a digital data environment as a digital bit stream is typically disrupted beyond any capability for error recovery other than complete retransmission. Their sources can be either natural (moisture, solar energy, lightning, ...) or manmade (static, electro-magnetic pulses, ...) and they are somewhat unpredictable and erratic. Since they occur intermittently, they are difficult to "capture" and quantify therefore difficult to characterize. They cannot be overcome by conditioning and therefore must be tolerated to some degree.

The following paragraphs contain more specific circuit properties and impairments. Each is referenced to its source document in the literature.

Voice frequency impairments from Fredrick [Ref. 29: p. 88b]:

Continuity and loss, C-message noise, C-notched noise, impulse noise, phase hits, gain hits, signal dropouts, intermodulation distortion, phase jitter, peak-to-average ratio (P/AR), envelope delay, and attenuation distortion.

Analog impairments from Bradley [Ref. 30]:

Additive impairments: background noise, impulse noise, crosstalk, and single-frequency interference.

Frequency division multiplexing impairments: phase jitter, phase hits, frequency translation, erratic primary-frequency supply, amplitude jitter, amplitude hits, and dropouts.

Pulse code modulation impairments: quantizing distortion, harmonic hits, timing jitter, timing bias, "aliasing" products (from 8 KHz sampling rate), and compandor mistracking.

Distortion: harmonic, and nonlinear.

Digital circuit impairments from FM 11-486-13 [Ref. 31: Chapter 7]:

Random transmission impairments: white noise, impulse noise, crosstalk, intermodulation noise, echoes, radio propagation fading, circuit interruption, phase changes, and phase jitter.

Systematic transmission impairments: path loss variations, nonlinear attenuation-frequency characteristic, delay distortion, harmonic distortion, frequency offset, bias distortion, characteristic distortion, and timing jitter.

Performance parameters as enumerated by Shoemaker in his thesis [Ref. 32: pp. 54-127]:

Level: loss, return loss, long term loss variation, attenuation distortion, bandwidth, and baseband loading.

Noise: signal uncorrelated difference, impulse noise, single frequency interference, and quantizing noise.

Distortion: envelope delay distortion, peak-to-average ratio, nonlinear distortion, incidental distortion, phase intercept distortion, frequency shift, phase jitter, incidental amplitude modulation, phase hits and gain hits, and dropouts.

Additional analog and digital circuit characteristics and their threshold levels are found in the MIL-STD-188-200 series for tactical systems.

2. LFICS Signal Characteristics

In his paper, Huebner provides a concise diagram summary of ULCS interconnectivity and explicit introduction to the diversity of LFICS signals [Ref. 33: p. 42]. The technical control facility must provide an interface for the interconnection of these media, and an appropriate suite of terminal and test, measurement and diagnostic equipment compatible with the various signal formats and rates. This information in the following is drawn primarily from [Ref. 2]. These characteristics are stated from the viewpoint of the main distribution frame (MDF) and form the basis for further examination of technical control interface requirements. The signal media, format and rates are summarized in Table 14 below. Stallings [Ref. 5: p. 46] provides the maximum data rates and bandwidths for the various media while the conditioned diphase signal format is explained quite well by Kirsch in his paper [Ref. 34: pp. 1613-1614].

TABLE 14

LPICS MEDIA AND SIGNAL CHARACTERISTICS

Circuit Media, Capacity and Bandwidth

Twisted pair (2-W), WD-1/TT
1 Mbps, 250 kHz

Twisted pair (4-W), WF-16
1 Mbps, 250 kHz

26-pair, Assault Cable CX-4566
1 Mbps, 250 kHz

Coaxial Cable, CX-11230
500 Mbps, 350 Mhz

Fiber Optic Cable, CX-(   )
1 Gbps, 1Ghz

Signal Format and Rate

Analog Voice, 2-W or 4-W,
(300-3400 Hz)

Digital Voice, 4-W, LPC or CVSD, cond. diphase,
(2.4 Kbps or 16/32 Kbps resp.)

Digital Data, 4-W, cond. diphase,
(16/32 Kbps)

Digital Channel Group, cond. diphase, TDM,
6/12/24/.../96 channels at 16 Kbps each,
(96/192/384/.../1152 Kbps per group resp.)

APPENDIX C

SUMMARY OF TECHNICAL CONTROL ALTERNATIVE EQUIPMENTS

The majority of the material for this appendix was drawn from the USMC Command and Control Master Plan [Ref. 2: Appendix D] and Jane's [Ref. 36: 446-448]. Certain specific information for the AN/TSQ-84 was obtained from its technical manual [Ref. 35: Chapter 1], and information for the AN/TSQ-111 was found in Martin-Marietta promotional literature [Ref. 12: p. B-2].

1. SB-4097/U Communications Patching Panel (Analog MDF)

The SB-4097/U is a simple analog main distribution frame. It has the capacity for (12) 26-pair cable connections for a total of 312 2-W terminations 156 in, 156 out). It has no inherent test or monitoring equipment.

2. AN/TSQ-84 Technical Control Facility

The AN/TSQ-84 is the coordination center for most analog, technical, communications control actions and is used to monitor, test, re-assign, and restore circuit service. It provides facilities for interconnecting, monitoring and testing voice frequency (VF) and data circuits in use within a tactical area communications system. Externally, facilities are provided to connect 432 individual 4-W VF circuits (216 in, 216 out). External connections are also provided to connect orderwire/alarm and intercommunication circuits from peripheral equipment. Limited local communications can be connected using WD-1/TT "slash wire." Within the AN/TSQ-84, interconnection is accomplished by normalling-through and by patching. Interface equipment is installed to permit interconnection with the Defense Communications System (DCS) and with commercial systems.

Test equipment and monitoring facilities for circuit quality control are included. Suitable communications equipment is included to provide for the functions of liaison, reporting and administration.

The technical characteristics of the AN/TSQ-84 are:

a) Power Requirements: 115/230V ac, 50 to 60 Hz 3-wire, single-phase; consumption is approximately 8.1 KW.

b) Connectivity: (72) connections for 26-pair assault cable (twelve 4-W circuits each).

c) Patch Panels: Main Distribution Frame (MDF), Monitor Patch Panel, Rapid Patch and Test Panel.

d) Line Conditioning: (48) variable attenuators, (18) LA-1R line amplifiers, (9) TA-957/G delay line equalizers.

e) FSK Equipment: (1) TH-22/G, high level space TTY equipment.

f) Special Communications: (6) 26-pair connectors for orderwire/alarm; (2) 26-pair connectors for control communications; (4) binding posts for intercommunications; pair 25 and 26 of each cable used for intercom circuits.

g) Operator's Communications Equipment: (2) SB-22/PT manual switchboards; Telephone, TA-312/PT; Telephone, TA-341/TT; (2) LS-147/FT intercoms; 20-Hz ring generator, TA-248A/TT.

h) Test Equipment: TTY Test Set, AN/GGM-15(V); Oscilloscope, AN/USM-296A; Spectrum Analyzer; Halcyon Multi-purpose Analog Test Set; Decibel Meter; Amplifier Interface Test Headset, AM-6789/G.

i) Physical Characteristics: standard S-280/G shelter; cube is 615, weight is 5800 lbs.

In summary, the AN/TSQ-84 is a manual or semi-automatic technical control facility. Connectivity is manual; and test and monitoring is manual or semi-automatic (series of tests by multi-function Halcyon test set).

3. AN/TSQ-84(M1) Modified Interface

The AN/TSQ-84(M1) is identical in form and function to the above with the exception of the additional interface capability with both coaxial and fiber optic cable systems. This modification to the existing 26-pair interface can take the form of external or internal CV-( ) devices which accept coaxial or fiber optic cable input, and deliver 26-pair compatible signals on the output; or actual hardware modification incorporated into the TCF shelter or MDF. Any power required could be provided by the TCF or local MEP. Note that these devices do not provide for encryption, buffering, multiplexing, etc., only the physical, electrical interface and conversion necessary (e.g.: light to electrical) to match coaxial or fiber optic cable to 26-pair.

4. AN/TSQ-84(M2) Included Digital Test Capability

The AN/TSQ-84(M2) has all of the features of the AN/TSQ-84, -84(M1) and includes the addition of a limited suite of digital test, measurement, and diagnostic equipment (TMDE). This enhancement could include such TMDE as: BER tester, bit pattern generator, digital line conditioning equipment, etc. Note that this does not include encryption, buffering, multiplexing, etc. With this upgrade, the AN/TSQ-84(M2) becomes a viable Level <2> TCF for use in analog and digital environments.

5. AN/TSQ-84A (Upgraded) Kit

The AN/TSQ-84A is a Communications Technical Control Center based on the AN/TSQ-84 (see above). The AN/TSQ-84A includes all of the capabilities of the AN/TSQ-84 for interconnecting, conditioning, testing and monitoring any of the 432 4-W VF circuits but with an additional specialized kit. The primary purposes of the upgrade kit, OA-8889/TSQ-84, are to provide for automated record keeping and to assist the operator in rapidly connecting test equipment to lines for testing, monitoring and troubleshooting tasks.

The AN/TSQ-84A upgrade equipment kit consists of: Minicomputer, Rolm 1602B; Display/Keyboard, HP-2645A with integral CRT, keyboard and dual magnetic tape cassettes; Monitor/Test Switch; Test Select Unit (TSU); Signal Matrix; Line Conditioning Equipment (LCE) Matrix; Three-way, 4-W Resistive Hybrid Bridge; High-Impedance Bridge; Teletype I/O, AN/UGC-74A(V)3; and High and Low Speed I/O Ports.

The computer, under program control, performs automatic recordkeeping tasks and acts as the controller for operator initiated testing or monitoring actions. The magnetic tape cassettes allow for program loading, operational program and data base storage. An additional feature of the AN/TSQ-84A is that other TCF's or communications management and control agencies have remote access to the data base.

The signal matrix assembly allows the connection of any one of the 432 4-W circuits to the test select unit (TSU) in either a "bridging" or termination configuration. The line conditioning equipment (LCE) matrix permits the connection of any circuits directly to the amplifiers, attenuators or delay line equalizers. The test select unit (TSU) is the interface between the computer's command outputs and the signal matrix for selection of the circuit to be tested. Test equipment is then connected to the TSU for conduct of the desired test or monitoring procedure.

In summary, the AN/TSQ-84A has the same capabilities as the AN/TSQ-84 but has computer assisted test/monitoring set-up, automatic record keeping, and remote data base access.

6. Communications Nodal Control Element, AN/TSQ-111

The AN/TSQ-111 is an element of the TRI-TAC network architecture. It is designed to manage communications resources throughout a node, monitor equipment and circuit quality, detect and isolate faults, and provide the communications security (COMSEC) equipment needed for a responsive, flexible network.

The CNCE is of modular design and can be adapted for deployments and communications networks of various sizes. It selects the optimal communications path through a multiple path grid network and uses available resources to accomodate stresses imposed on the network by dynamic users needs and by grid disruptions both inside and outside the node.

The AN/TSQ-111 is designed to co-exist with current tactical switching and user terminal facilities. It can be configured to receive, condition and retransmit analog data. Alternatively, the technical controller can convert the analog data to digital data using continuously variable slope delta (CVSD) encoders, and transmit it to the user terminal for decoding back into analog form. The CNCE can accept inventory US Army six-bit pulse code modulation (PCM) group data, multiplex this with TRI-TAC channels to form a TRI-TAC group, and send the combined group of channels over a TRI-TAC transmission system.

The AN/TSQ-111 also provides bulk encryption and key distribution, reports the node's status to higher network planning and control elements, and responds to high level direction. It automatically and continuously assesses all communications equipment throughout the node, provides real-time detection of faults in the circuit, and sets up an alarm when corrective action is required.

The principal features of the AN/TSQ-111 for the US Air Force systems are:

a) Digital: (33) external coax connectors, (32) group rate modems, (12) group encryption devices, (54) digital telephone modems, (24) digital cross connects for groups and (862) for channels.

b) Analog: (30) external 26-pair connectors, (390) total MDF appearances, (24) analog to digital conversion channels, (72) automatic analog test channels.

The major AN/TSQ-111 subsystems are:

a) Analog Patch and Test: provides manual patching, line conditioning, automatic analog testing, manual (backup) testing, monitoring, and routing of all circuits.

b) Digital Patch and Test: provides line modems, manual patching, automatic patching (channel reassignment function), and automatic testing of all digital circuits.

c) Fault Detection and Isolation: provides processing of internal BITE data, telemetry fault and performance data, circuit switch status report data, automatic analog test results, automatic digital test results, and channel reassignment status to detect and isolate faults in the CNCE and other nodal equipment.

d) Processor Subsystem: provides processing and storage of data, control of automatic testing, automatic patching, fault detection and isolation procedures, and processing for Controller interface with the data base.

e) Control Subsystem: provides the entry controls and display devices for the man/machine interface between the Controller and the processor subsystem.

f) Control Communications Subsystem: provides intercom and analog voice, digital voice, teletype, and data orderwire facilities between the CNCE and other nodal assemblages and between the CNCE and TCCF equipment located at other nodes.

g) Timing Subsystem: provides the clock and synchronization functions necessary for maintaining bit integrity, framing, and COMSEC equipment synchronization by the various digital devices such as modems, multiplexors, and the channel reassignment function.

h) COMSEC Subsystem: provide message encryption as necessary for end-to-end secure communications.

The AN/TSQ-111 entered production in 1983 and will eventually be deployed at numerous locations throughout the US Air Force tactical air control systems to provide commanders with management facilities and nodal control. It will replace. through attrition, large quantities of obsolete, out-of-production analog equipment, including: AN/TSQ-84, AN/TCC-72, AN/TCC-62, and AN/TCC-73 multiplex shelters; AN/TSC-62 Air Force TCF; and AN/MSC-32 and AN/MSC-31 planning and engineering shelters.

In summary, the AN/TSQ-111 is the TRI-TAC standard, fully automated analog and digital TCF with manual backup capabilities.

7. Unit Level Circuit Switch (ULCS), AN/TTC-42 (Enhanced)

The AN/TTC-42 (Enhanced) is based upon the AN/TTC-42. The AN/TTC-42 is the major circuit switch component of the Unit Level Circuit Switch (ULCS) family. The ULCS are designed for the TRI-TAC system to provide tactical military forces with a transportable, reliable, secure and survivable automatic communications switch. The AN/TTC-42 is compatible with the analog switched systems of the 1970's and the integrated, digital, secure communications systems of the future for tactical air, land and sea forces by providing plug-in interchangeable terminations for both scenarios under the control of a common computer. The switch will operate with various mixes of digital and analog loops and trunks in secure and non-secure modes.

The AN/TTC-42 provides 150 lines (mixed analog/digital trunks and loops) for sole user and switched service for up to 144 channels derived from TDM groups. It has a capacity for 7 digital trunk groups (DTG) including 6 with up to 18 channels (16/32 kbps) per group and one with up to 72 channels per group. Automatic switching includes: loop-to-loop, loop-to-trunk, trunk-to-loop, and trunk-to-trunk. The AN/TTC-42 is transportable by sea, land and air in a standard S-280/G military shelter. The maintenance/supervisor position is supported by interactive software and the switch features automated fault isolation and software and hardware security protection. It has integral COMSEC equipment and is designed to withstand nuclear effects. It weighs approximately 4500 lbs. and requires 3KW prime power.

The AN/TTC-42 (Enhanced) has the capability to perform multiplexing and limited communications technical control functions. It has an analog and digital patch panel, and automatic go/no-go monitoring of channel and trunk groups.

There are additional engineering change proposals (ECPs) which (if approved) will increase the analog capacity of the switch and add test and analog line conditioning equipment to enhance the switch's capability in a stand-alone environment.

8. Circuit Switch/Technical Control Facility, AN/TTC-39A

The AN/TTC-39A combined circuit switch and technical control facilty is based on the AN/TTC-39. The basic AN/TTC-39 circuit switch is a 4-W central office exchange providing automatic switching services for both analog and digital voice and data traffic at all echelons of a theatre-levels communications system. Designed as the nucleus of the TRI-TAC communications system, the AN/TTC-39 interfaces with the US AUTOVON and AUTODIN networks, with NATO communications systems, and with a wide array of inventory and planned TRI-TAC subscribers, switches, COMSEC equipment, transmission systems and technical control facilities.

The AN/TTC-39 provides fully automatic tandem access over a maximum of 426 lines in its single S-280/G shelter configuration, and up to 660 lines when housed in two S-280 shelters.

The switch is equipped with both analog and digital switch matrices that can be exchanged both mechanically and electrically at any time, according to need. Thus as tactical communications equipment evolves from the predominantly analog systems currently in use to the all digital TRI-TAC equipment of the future, the AN/TTC-39 can evolve to serve its users.

The AN/TTC-39A is an upgrade of the AN/TTC-39 circuit switch to incorporate automated technical control capabilities. The AN/TTC-39A includes standard equipment components from the AN/TSQ-111 automated technical control facility. The extent of these modifications and the capabilities of the AN/TTC-39A are not specified at this time.

APPENDIX D

FUNCTIONAL AND SYSTEM BLOCK DIAGRAMS

This appendix contains a functional block diagram of the desired technical control facility described in Chapter IV (Figures D.1 and D.2), and a generic LFICS node (Figure D.3) which is subsequently referred to in the presentation of the various alternatives (Figures D.4 to D.7). Notice that there is not one figure for each alternative. Many of the alternatives are similar with the exception of the equipment nomenclatures. They have been combined into a set of four basic configurations with the differences noted in the accompanying text.

1. Desired Technical Control Facility

The desired technical control facility described in Chapter IV is a fully automated, analog and digital facility. In Figure D.1 below, the basic computer suite and associated automatic controller are shown. In Figure D.2, the functional block diagram of the entire facility is presented. All connections are shown by a single line, but represent multiple paths. There are specific control, COMSEC and monitor and test points within the functional architecture of the facility which are identified below. Note that each patch panel in the facility has a manual or "physical" capability. This physical connectivity will remain in the absence of power.

A - The computer and it's associated controller will connect to the facility and its resources at all points A as shown in Figure D.2. There is no implication that all these points are electrically the same, only that a controller interface exists. It is also noted that since the facility has manual and semi-automatic back-up capability, the controller can be disabled with no impact on connectivity or any other functions of the facility. In this latter case, actions which would normally be performed by the controller automatically, will be performed by the facility operator either manually or semi-automatically.

▽ - Any required applications of appropriate communications security (COMSEC) equipment will be made at the points identified as ▽ in Figure D.2 below.

(TP) - Finally, and most importantly, the application of test, measurement and diagnostic equipment (TMDE) can be made at any of the points identified as (TP) for test point. Although not all points (TP) are electrically identical, provision will be made at each for application of an appropriate array of TMDE. The connections will be made automatically by the computer and controller, or manually, semi-automatically by the operator. Connections will take one of four forms: parallel, series, terminal and loop-back as required for the particular monitoring or test set-up.

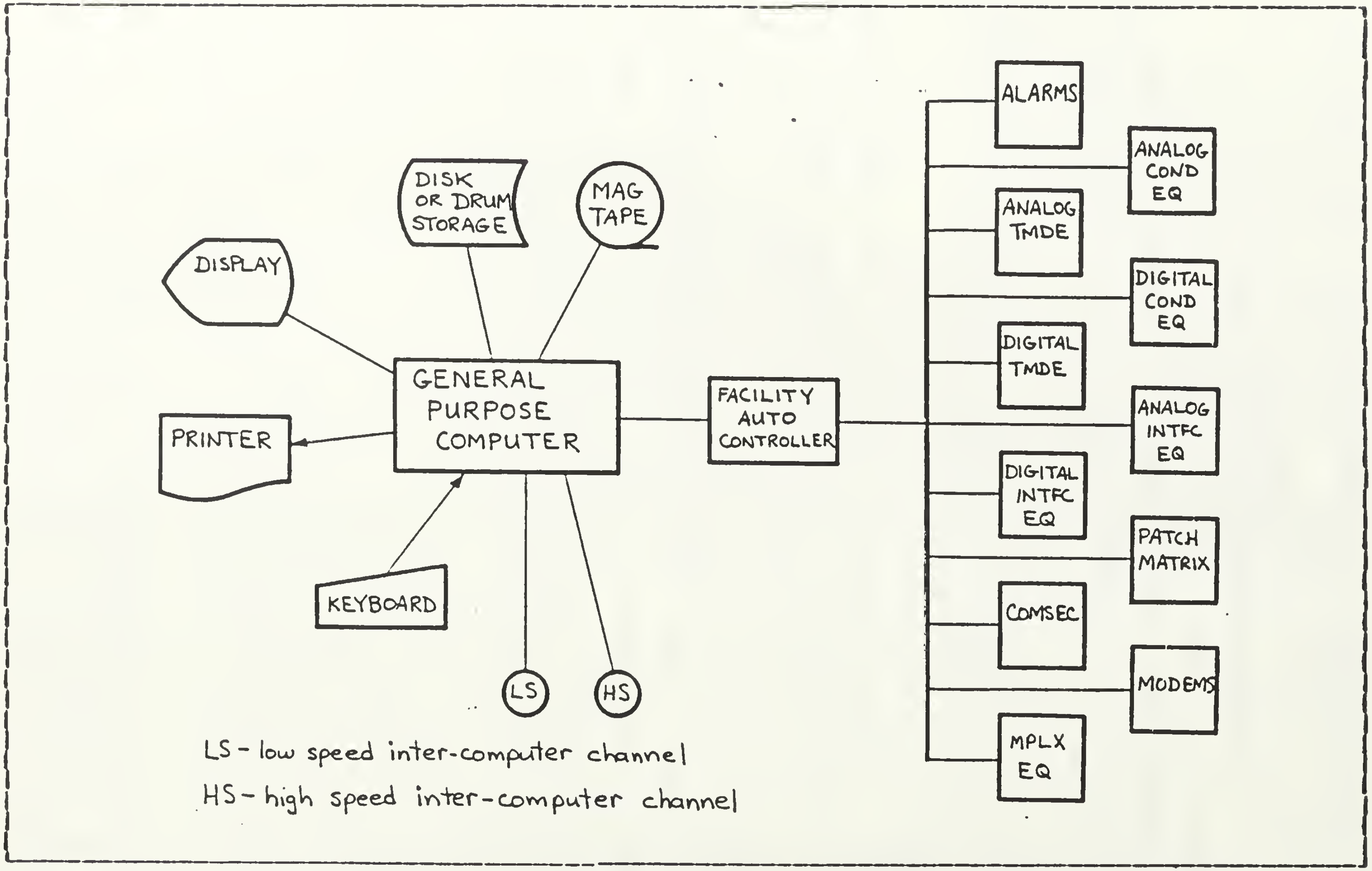


Figure D.1 Computer Suite and Facility Controller.

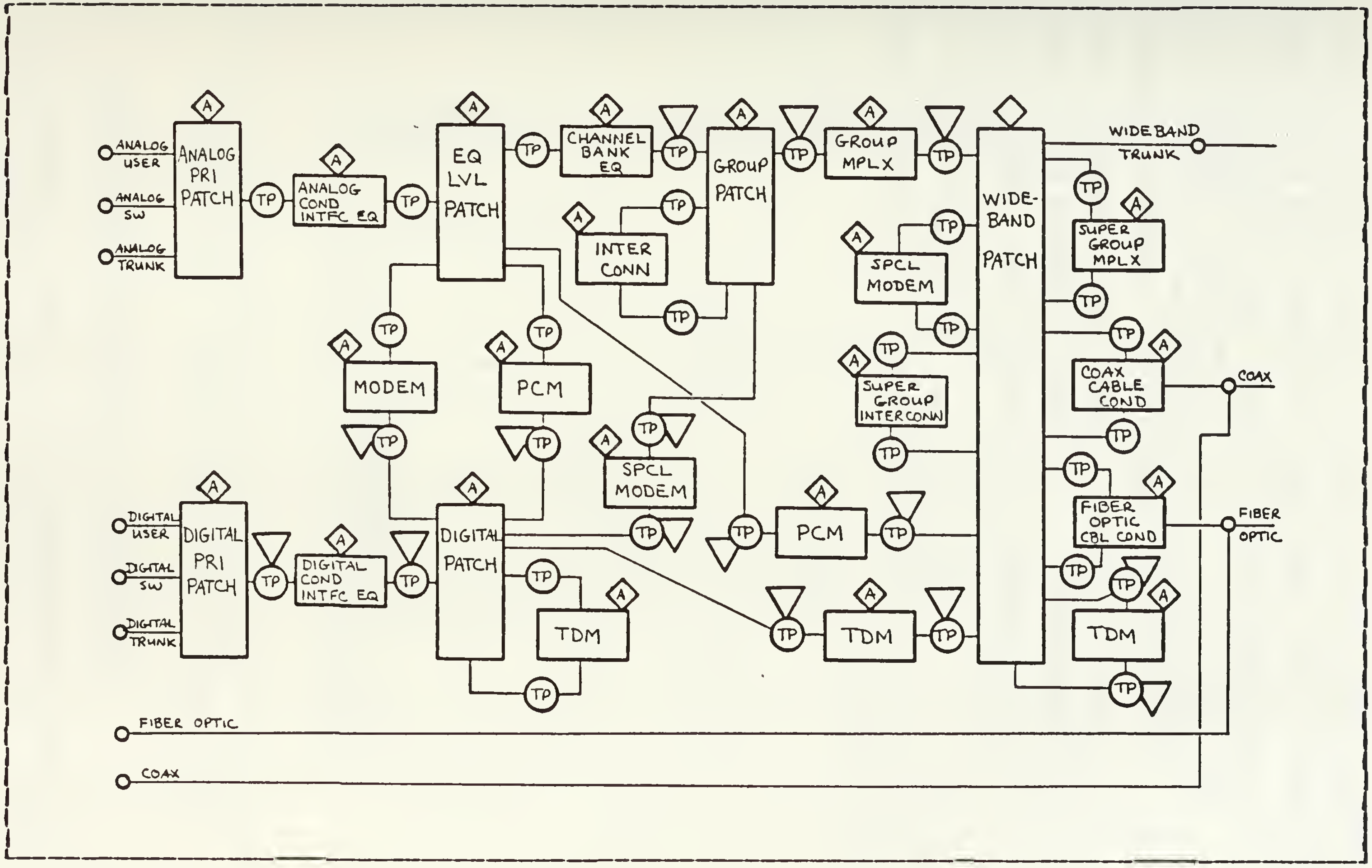


Figure D.2 Desired Automated Technical Control Facility.

2. Generic LFICS Node

The generic LFICS node shown in Figure D.3 below depicts only the essential characteristics of the architecture. There are users in three categories: communications centers, command and control centers (tactical and administrative), and individual subscribers. Their connection is shown as a single line but implying many analog or digital circuits as appropriate. Likewise, there are numerous single and multi-channel radio transmission media consolidated into the single line shown. The primary focus of the alternatives is on the area of technical control and switching facilities which are defined in subsequent discussion and figures.

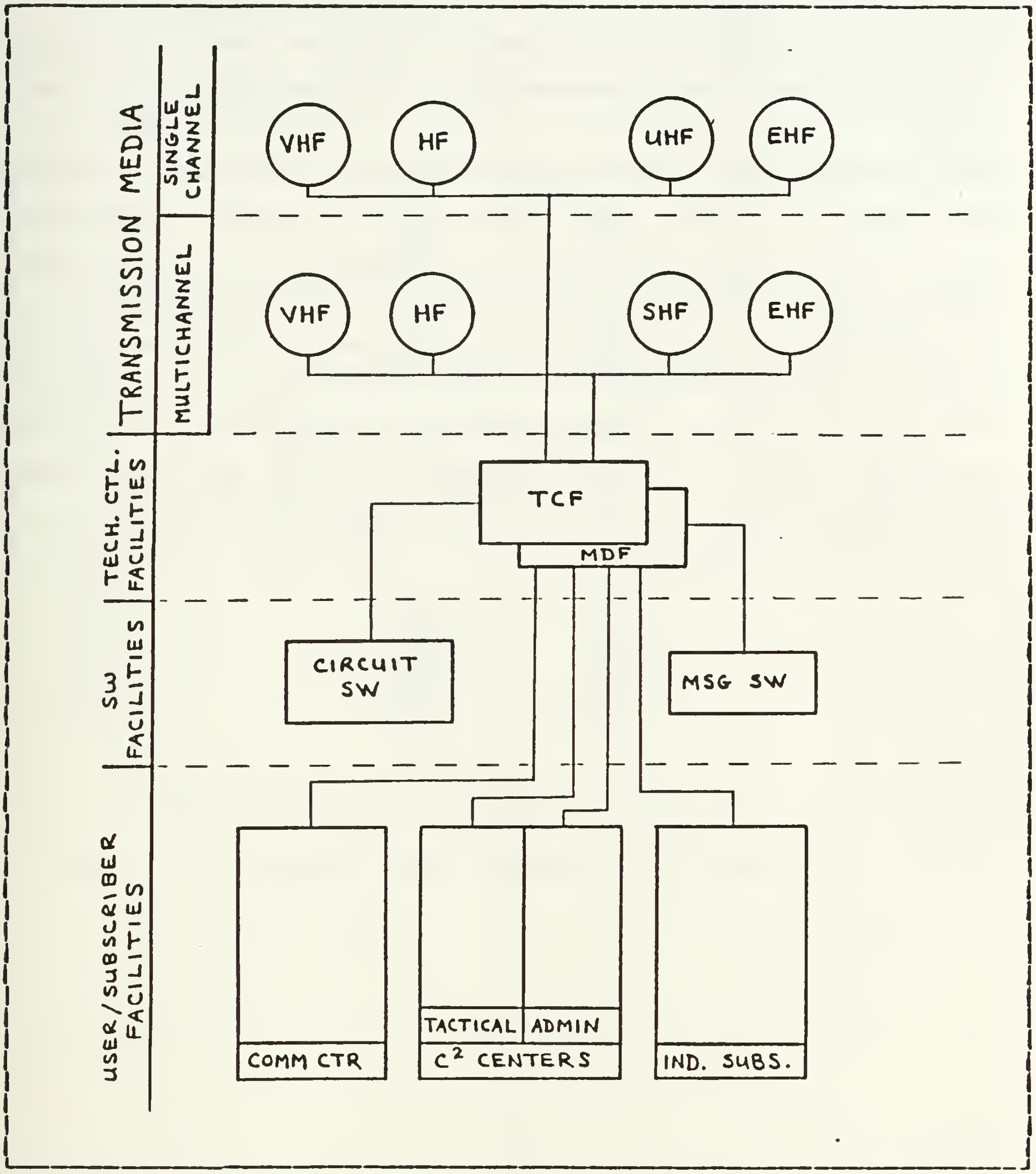


Figure D.3 Diagram of Generic LFICS Node.

3. System Block Diagrams of Alternatives

The primary focus of the alternatives below is on the area of technical control and switching facilities. That is, they illustrate which equipment is considered the primary technical control facility and how much (if any) of the technical control capability is provided by a multi-purpose SW/TCF facility. When a switching equipment is shown overlapping the boundary between switching functions and technical control functions, the explicit statement is that it is performing the latter functions to some degree. Recall that the ideal situation is for all circuits to be accessible at a central location, a main distribution frame (MDF). This is the case in the first two (1, 2) and last two (11, 12) alternatives but not the others. The others have all analog circuits appearing at the MDF but various quantities of the digital circuits appearing relative to the capabilities of the TCF.

a. Alternatives 1 and 2 shown in Figure D.4 exhibit the configuration if the AN/TTC-39A or AN/TTC-42 (Enhanced) were chosen as combined SW/TCF replacements for the AN/TSQ-84.

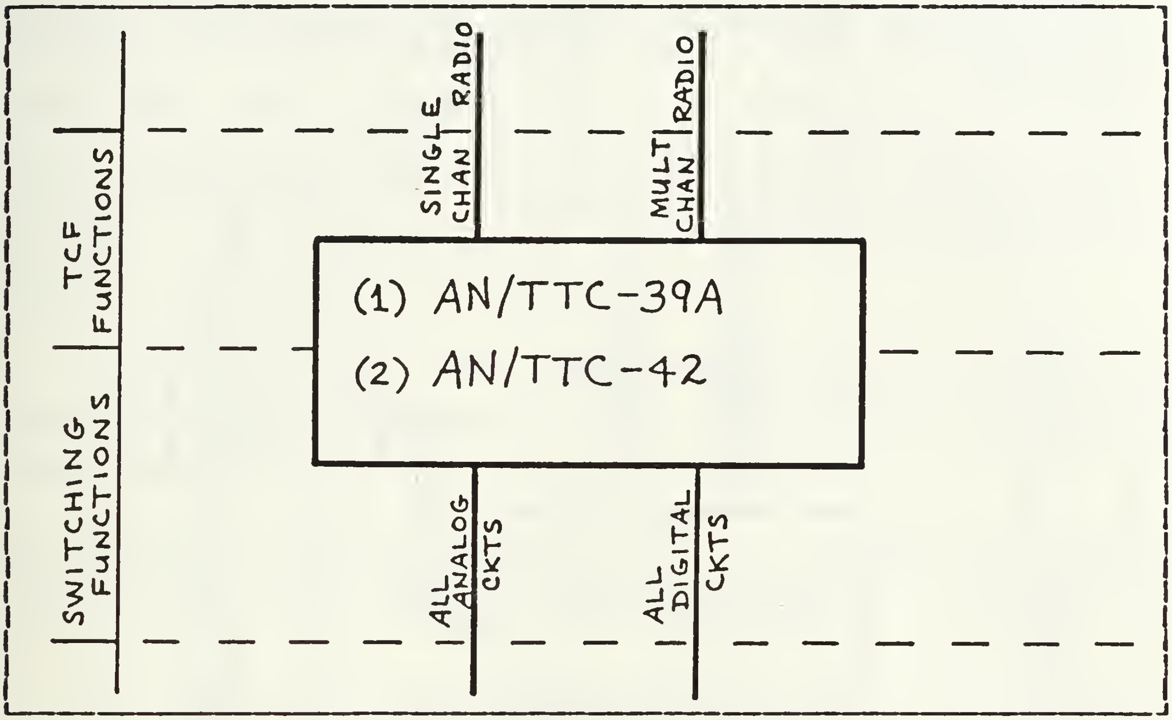


Figure D.4 System Block Diagram of Alternatives 1 and 2.

b. Alternatives 3 and 4 both utilized the AN/TTC-42 (Enhanced) as the primary TCF for digital circuits. In both alternatives, all analog circuits are routed through the associated AMDF or HMDF. In the latter case, some digital circuits will be routed through the HMDF rather than the AN/TTC-42.

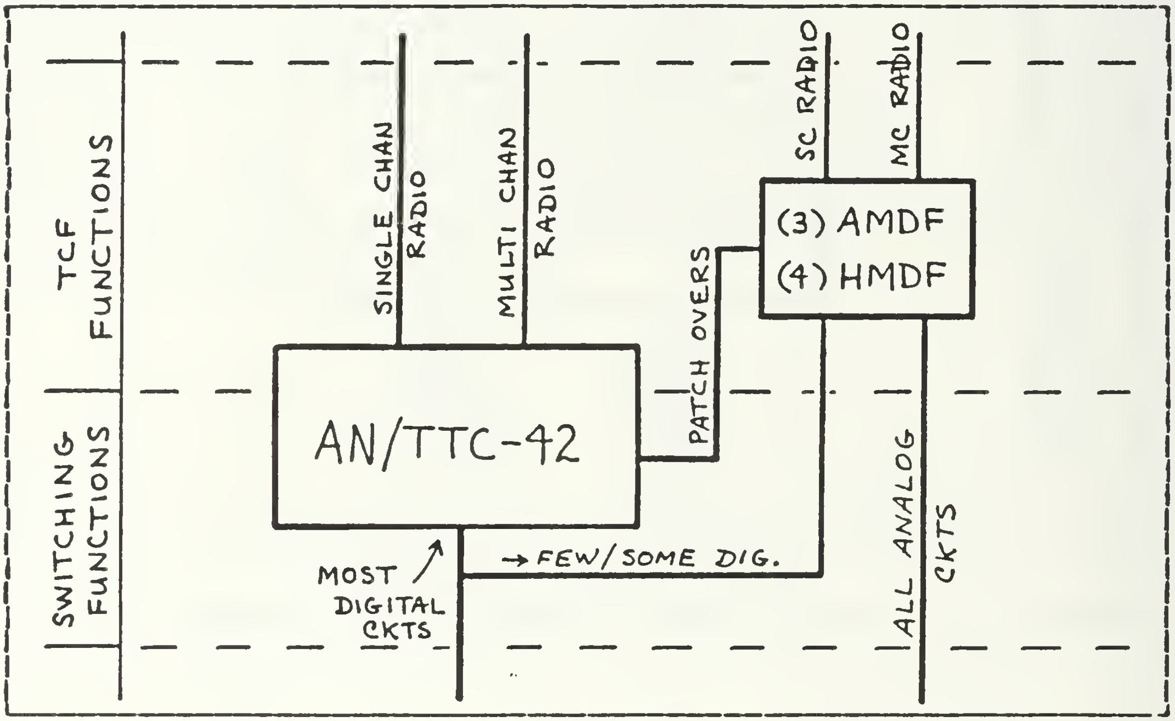


Figure D.5 System Block Diagram of Alternatives 3 and 4.

c. Alternatives 5, 6, and 7 use the AN/TTC-42 (Enhanced) together with the AN/TSQ-84, -84(M1), and -84(M2) respectively. These versions of the AN/TSQ-84 were described in the discussion of alternatives and in Appendix C. Alternatives 8, 9, and 10 utilized the same progression of increased digital capabilities but with the AN/TSQ-84A (Upgraded) as the baseline TCF. In each of the six cases, all of the analog circuits are routed through the AN/TSQ-84 "family" TCF/MDF. The difference between the various alternatives is in the quantity of digital circuits routed through the TCF/MDF vice the switch.

The AN/TSQ-84 (or -84A) would receive only those digital circuits which are compatible with twisted-pair or 26-pair cable interface.

The AN/TSQ-84(M1) (or 84A(M1)) accepts twisted-pair/26-pair compatible circuits in addition to those which are compatible with a coaxial and fiber optic interface.

Recall that the basic AN/TSQ-84 (or -84A) and the above (M1) enhancement both lack the capability to perform other than rudimentary digital monitoring and test. The -84(M2) (or -84A(M2)) has both the required interface and the additional monitoring and test capabilities. It would, therefore, have the majority of the digital circuits routed through it's MDF.

It each of the alternatives, the remaining digital circuits (if any) would be routed through the AN/TTC-42 (Enhanced) for TCF actions. All six alternatives are shown in Figure D.6 below.

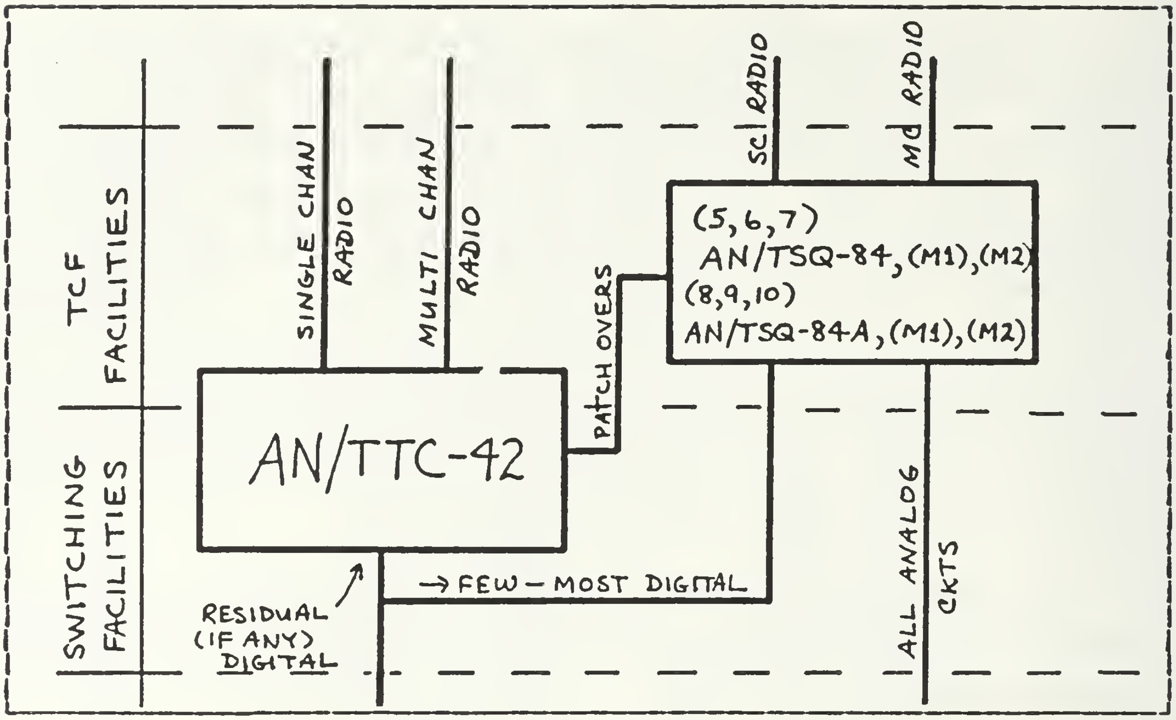


Figure D.6 System Block Diagram of Alternatives 5 through 10.

d. Alternatives 11 and 12 place all technical control emphasis on a primary, full-capability TCF, either the AN/TSQ-111 or AN/TSQ-xxx "new start." The switching equipment is connected to the MDF in either of the mentioned TCF's and not to the subscribers. This provides the ideal central appearance for all analog and digital circuits at the single MDF.

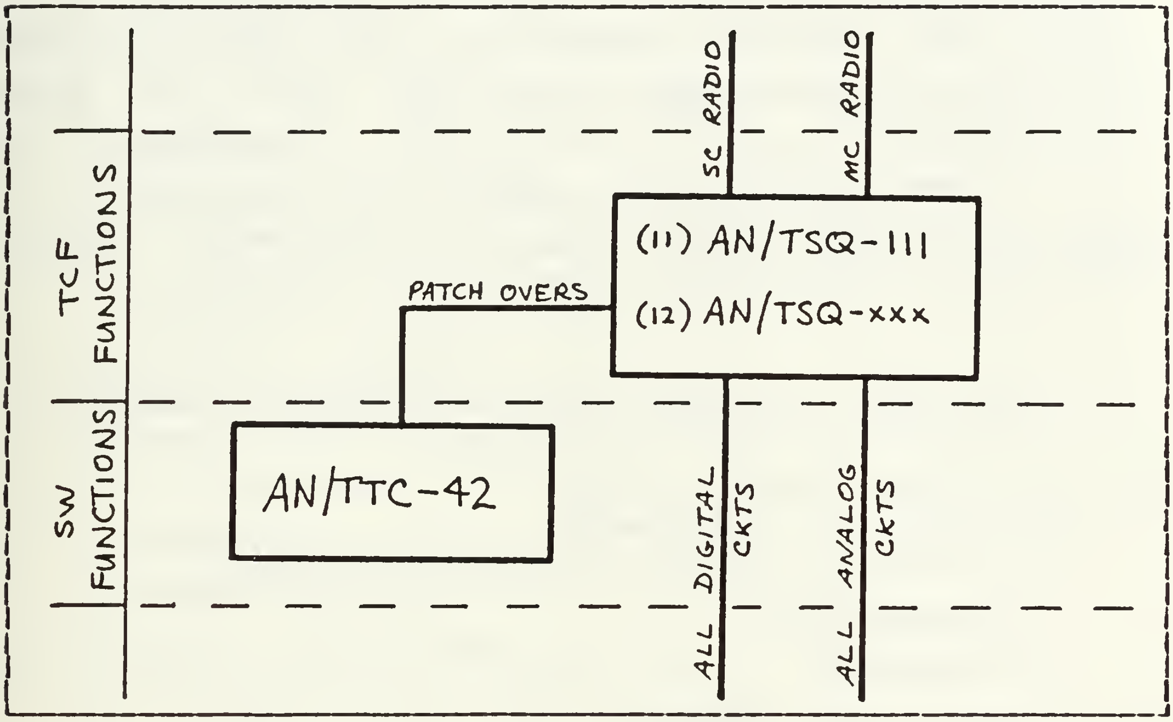


Figure D.7 System Block Diagram of Alternatives 11 and 12.

APPENDIX E

DEVELOPMENT OF CRITERIA FOR DECISION THEORY PROCESS

The following collections of criteria include items drawn from acquisition management, system design principles, US Marine Corps statements of policy [Ref. 2: pp. 1-4 & 1-7], discussion with other communications professionals in the military and academic communities, and general knowledge. They are not categorized (other than source) or defined below but are presented as an initial "brainstorming" list in an attempt to capture all possible relevant criteria. It will be noticed that not all of the following potential criteria are quantifiable above an ordinal scale.

1. Acquisition Management and System Design Principles

a) Mission Analysis
b) Operational Requirements
c) Long Range Planning and Program Stability
d) Affordability
e) Timeliness
f) Acquisition Strategy
g) Participating Activities
h) Industrial Resource Analysis
i) Facility Construction
j) Cost Estimates
k) Goals, Thresholds, and Threshold Ranges
l) International Defense Cooperation
m) Economical Production Rates
n) Test and Evaluation
o) Independent Cost Analysis
p) Competition

q) Specifications and Standards
r) Standardization and Interoperability in Engineering Design
s) Pre-planned Product Improvement
t) Quality
u) System Readiness, Support and Personnel
v) Realiability and Maintainability
w) Deployment Requirements
x) System Safety
y) Physical Security
z) Nuclear and Chemical Hardness, Survivability and Endurance
aa) Producibility and Production Planning
ab) Contractor's Production Capability and Contractor Productivity
ac) Computer Resources
ad) Data Management
ae) Metric Units of Measurement
af) Electromagnetic Spectrum and Other Spectrum Allocation
ag) Energy Efficiency
ah) Environmental Impact
ai) Post Production Support
aj) Administrative and Business Applications for Automated Information Systems
ak) Cost Visibility and Control
al) Industrial Modernization Improvement
am) Evolutionary Development and Acquisition of Command and Control Systems

2. US Marine Corps Statements of Policy

The following is a highly summarized and paraphrased reproduction of the US Marine Corps policy statements found in the Command and Control Master Plan [Ref. 2: pp. 1-4 to 1-7] which apply to the acquisition of all command and control systems and equipment. The listed sequence corresponds with the cited document.

a) Satisfaction of operational requirements is paramount.
b) Operation is required in combat, garrison and (as necessary) aboard amphibious shipping.
c) Maximize the utilization of other service, government agency, or joint developments before unilateral action.
d) Maximize the use of standard USMC or other off-the-shelf components.
e) Manual back-up to automated systems is mandatory.
f) Minimumize system complexity and sophistication.
g) Maximize the integration of ground/air systems.
h) Interface requirements will be defined to maintain inter/intraoperability.
i) TDS data exchange standards will be included in design.
j) Interoperability with other services and allies is necessary.
k) Meet JINTACCS including JTAO and TADIL J standards for interoperability.
l) System software will use DOD approved high-order language.
m) Administrative, physical, personnel and COMSEC considerations.
n) Modularity of components will be maximized to facilitate compatibility.
o) Continuity of operations in degraded conditions. Reliability, redundancy, maintainability, and reconfiguration capability to allow graceful--not catostrophic--degradation in the face of equipment loss due to malfunction or enemy action.

p) LFICS will provide all for all analog and digital data transfer and satisfy all communications mission requirements.

q) Tactical multichannel system will transition to common-user, all digital system.

r) Systems will operate in a high EW threat environment.

s) Emphasis on reliability and maintainability in integrated logistics support (ILS) during the acquisition process.

t) A single automated data processing support concept will be used.

u) Tactical equipment must be interoperable with automated information systems (AIS).

v) MSARC level pragrams subject to configuration management (CM) at functional baseline.

w) MOS training requirements, skill levels identified prior to MSARC III.

x) World-wide operability. Transportability by sea, air, and rail without impediment to the mobility of the operational forces. Infantry battalion equipment will be man-portable.

y) Systems will operate on power provided by: ships, commercial sources, batteries and standard US Marine Corps MEP sources.

z) Minimize shelterization of equipment or use standard US Marine Corps shelters.

3. Other Communications Officers

Performance, maintainability, cost, risk, reliability, producibility, manpower/personnel life cycle costs (LCC), training requirements, personnel quantity and skill levels, and affordability.

4. A List of "-ilities"

Affordability, maintainability, reliability, producibility, interoperability, intraoperability, transportability, mobility, vulnerability, survivability, suitability, supportability, flexibility, testability.

5. Generally Desireable Measures

Mission effectiveness, speed, analog capability, digital capability, quantity of analog circuits, quantity of digital circuits, power requirements, weight, cube, technological risk, schedule risk, manual back-up capabilities, "fail-soft" capabilities, redundancy and simplicity.

APPENDIX F
DETAILS OF DECISION THEORY PROCESSES

1. Assigning Values to Long Term Alternative Vectors

The ten criteria for evaluation of the long term alternatives are: digital performance (DP), analog performance (AP), manual back-up capability or "failsoft" (MBU), standard USMC/off-the-shelf (STD), interoperability (IOP), system complexity index (SCI), technological risk (TR), timeliness/availability (T/A), planned upgrade to all digital (PIP), and cost ($$).

The tabulated ranks of Table 15 result in the long term alternative vectors shown in Table 16 below and in Table 3 in the main body.

2. Descriptive Example of Aspiration Relaxation Process

For the puposes of this example of aspiration with relaxation, let us assume the following conditions:

a) We are working in a 3-space octant with all positive values.

b) The rejection set is defined as all points contained within the rejection space, inclusive of the surface but exclusive of the corner points.

c) The acceptance set is defined as all points outside the rejection space which were corner points at one iteration of the relaxation process.

TABLE 15

ASSIGNMENT OF LONG TERM VALUES

Criteria	Nom/Ord Scale	Alternative(s)
DP	<0>	
	<1>	
	<2>	2, 3, 4, 5, 6, 7, 8, 9, 10
	<3>	1, 11, 12
AP	<0>	
	<1>	2, 3, 4
	<2>	5, 6, 7, 8, 9, 10
	<3>	1, 11, 12
MBU	poor	
	fair	1, 2
	average	3,4
	good	5, 8, 11
	excellent	6, 7, 9, 10, 12
STD	poor	
	fair	
	average	1, 8, 9, 10
	good	4, 6, 7, 11
	excellent	2, 3, 5, 12
ICP	poor	
	fair	
	average	1, 2, 3, 4
	good	5, 6, 7, 8, 9, 10
	excellent	11, 12
SCI	low	
	below average	
	average	3, 4, 5, 6, 7
	above average	2, 8, 9, 10
	high	1, 11, 12
TR	low	2, 3, 4, 5
	below average	6, 7
	average	1, 8, 9, 10, 11
	above average	12
	high	
T/A	poor	
	fair	1
	average	1, 11, 12
	good	8, 9, 10
	excellent	2, 3, 4, 5, 6, 7
PIP	poor	
	fair	
	average	3, 5, 6, 8, 9
	good	4, 7, 10
	excellent	1, 2, 11, 12
$$	low	2, 5
	below average	3, 4, 6
	average	7, 8, 9
	above average	10, 11
	high	1, 12

TABLE 16

SUMMARY OF SCORED LONG TERM ALTERNATIVE VECTORS

Alt	Long-Term Vector
1	(3,3,2,3,3,1,3,3,5,1)
2	(2,1,2,5,3,2,5,5,5,5)
3	(2,1,3,5,3,3,5,5,3,4)
4	(2,1,3,4,3,3,5,5,4,4)
5	(2,2,4,5,4,3,5,5,3,5)
6	(2,2,5,4,4,3,4,5,3,4)
7	(2,2,5,4,4,3,4,5,4,3)
8	(2,2,4,3,4,2,3,4,3,3)
9	(2,2,5,3,4,2,3,4,3,3)
10	(2,2,5,3,4,2,3,4,4,2)
11	(3,3,4,4,5,1,3,3,5,2)
12	(3,3,5,5,5,1,2,3,5,1)

d) Alternative points which are outside the rejection space and not elements of the acceptance set are permanently discarded as unacceptable.

e) The example alternative points are: (1,3,2), (2,1,1), and (3,2,3).

f) The example initial aspiration vector is: (<2,3>,<2,3>,<2,3>). And,

g) The successively relaxed aspiration vectors (and examples of the spaces they define) are:

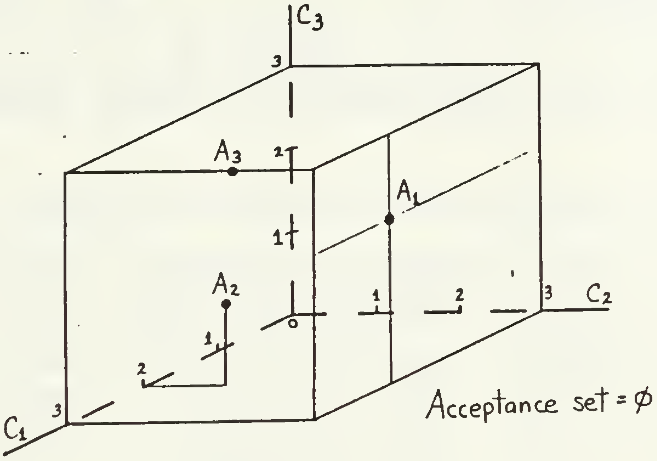
0	(3,3,3)	Figure F.1 (a)
1	(3,3,2)	
2	(3,2,3)	Figure F.1 (b)
3	(3,2,2)	
4	(2,3,3)	
5	(2,3,2)	
6	(2,2,3)	
7	(2,2,2)	Figure F.1 (c)

The initial aspiration vector elements are interpreted as <a,b> meaning that the acceptance range for that dimension is the interval (a,b) inclusive. When the initial aspiration rejection space is constructed as shown in Figure F.1 (a), we see that all of the alternative points are rejected since they are contained within the space. In Figure F.1 (b) the rejection space has been relaxed through 2 iterations. The current aspiration vector is: (3,2,3). We see that alternative "3" is now at a corner of the rejection space and therefore, enters the acceptance set. Notice that alternative "1" is outside the rejection space but was not a corner point so it is rejected as unacceptable. Alternative "2" remains a candidate since it is contained in the rejection space. This step-wise, right to left relaxation (shrinkage) of the rejection space continues until the lower limits of the aspiration vector are reached. This is shown in Figure F.1 (c) and we note that alternative "2" remains contained in the rejection space, therefore is rejected as unacceptable at this final step in the process.

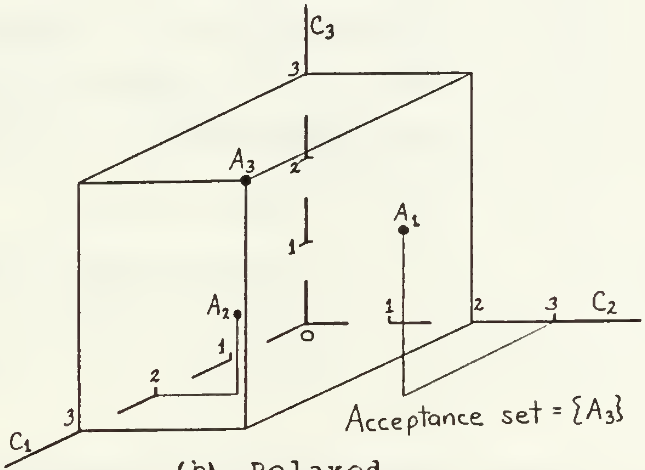
Thus, we would have identified the order in which the alternatives left the rejection space and entered the acceptance set. This ordered entry into the acceptance set carries with it the implication of a preference among alternatives.

3. Initial Long Term Aspiration Vector

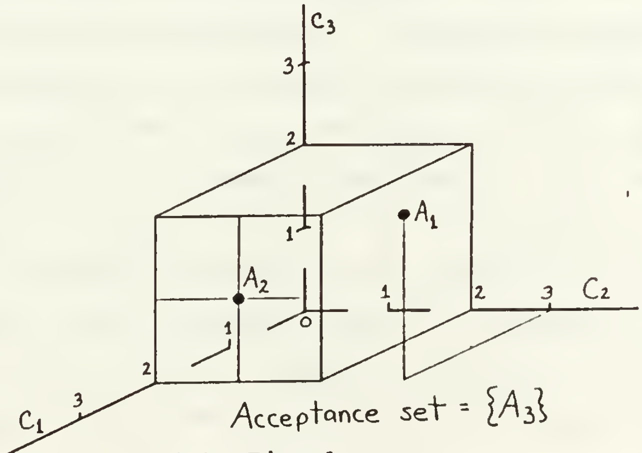
Let the initial threshold aspiration vectors for this application be as shown in Table 17 following. The range entries <a,b> are interpreted as meaning that the range of acceptable nominal or ordinal values for that criterion attribute is "a" to "b" inclusive. An "X" represents a don't care which means the aspiration acceptance region includes all values for that criteria. We should take the best value available when more than one alternative meets all of the other threshold levels.



(a) Initial



(b) Relaxed



(c) Final

Figure F.1 Aspiration Rejection Space and Relaxation.

TABLE 17

INITIAL LONG TERM ASPIRATION LEVEL THRESHOLD VECTOR

(<2,3>,<1,3>,<4,5>,<4,5>,<4,5>,X,<3,5>,<3,5>,<4,5>,X)

DP	<nominal,maximum>	<2,3>
AP	<minimum,maximum>	<1,3>
MBU	<good,excellent>	<4,5>
STD	<good,excellent>	<4,5>
IOP	<good,excellent>	<4,5>
SCI	"Don't care"	X
TR	<low,average>	<3,5>
T/A	<average,excellent>	<3,5>
PIP	<good,excellent>	<4,5>
$$	"Don't care"	X

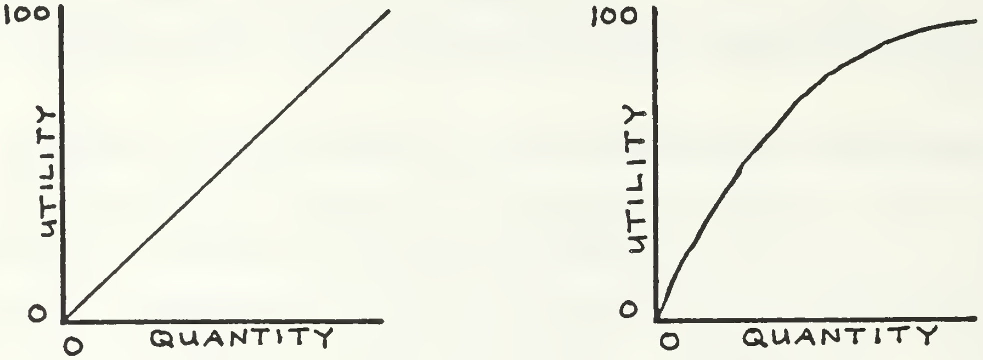
4. Some Typical Utility Functions

Prior to application of the dimensional analysis and Mann-Whitney processes, it was necessary to transform the criteria quantities within the alternative vectors from ordinal to utility values. As noted in Chapter VI, the assumption of a positive linear utility curve is made for simplicity and due to lack of data supporting any other choice. An example of a positive linear utility curve is shown in Figure F.2 (a). This curve represents linear utility and constant marginal utility, that is, each unit of quantity is equally valued in terms of utility.

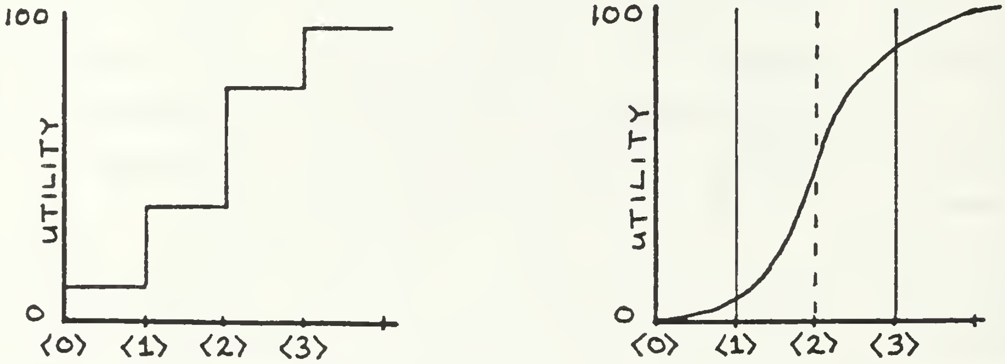
A criteria such as cost ($$) is better fitted to a utility curve such as shown in Figure F.2 (b). This curve represents non-linear utility and declining marginal utility. The value of the input dollars in terms of utility growth declines as the quantity increases (e.g.: diminishing returns).

Performance related criteria, such as (AP), or (DP) are best fitted to curves such as in Figure F.2 (c) or (d). Choice of one or the other depends on whether the increments of performance provide discrete or continuous gains in utility. The former, Figure F.2 (c), is a monotonic non-decreasing utility function with step-wise, discrete gains in utility. The latter, Figure F.2 (d), is more interesting in that it exhibits the characteristic of increasing mari-ginal utility to the left of the critical inflection point, and then decreasing marginal utility to the right. It can be seen that if the item or system fails to meet an arbitrary minimum, it has little utility until it reaches at least that point where marginal utility increases sharply. Likewise, if it exceeds the maximum required capability, the marginal utility of additional improvement drops off sharply.

These have been just a few examples of how the criteria of this study may be described by other than a positive linear utility curve. For a more complete presentation, see Easton [Ref. 25: pp. 148-150]. There is no data available of suitable scale to enable selection from among this variety for this application. So a compromise positive linear curve of constant marginal utility was chosen as the best approximation to the unknown, true curve, for each criteria.



(a) Pos Linear (b) Decreasing



(c) Monotonic N-D (d) Inflection

Figure F.2 Several Examples of Simple Utility Curves.

5. Vector to Scalar Conversion in 3-Space

In this 3-space example, there is an axis for each of three critera: C1, C2, and C3. Each criteria value represents a projection of the alternative vector on that criterion axis in the 3-space. As we move away from the worst possible alternative, the origin, in any single dimension (C1, C2, or C3), the scalar length of the distance vector from the origin to the current point is increasing. This is equivalent to an improvement of the ranking across the criteria since each value represents a "bigger is better" score.

In Figure F.3 below, this process is demonstrated for hypothetical alternative vectors: A(1)=a(1,1),a(1,2),a(1,3) and A(2)=a(2,1),a(2,2)a(2,3). Suppose that the length of alternative vector A(1) is ">" the length of vector A(2), this implies that A(1) is a better choice than A(2) in this example.

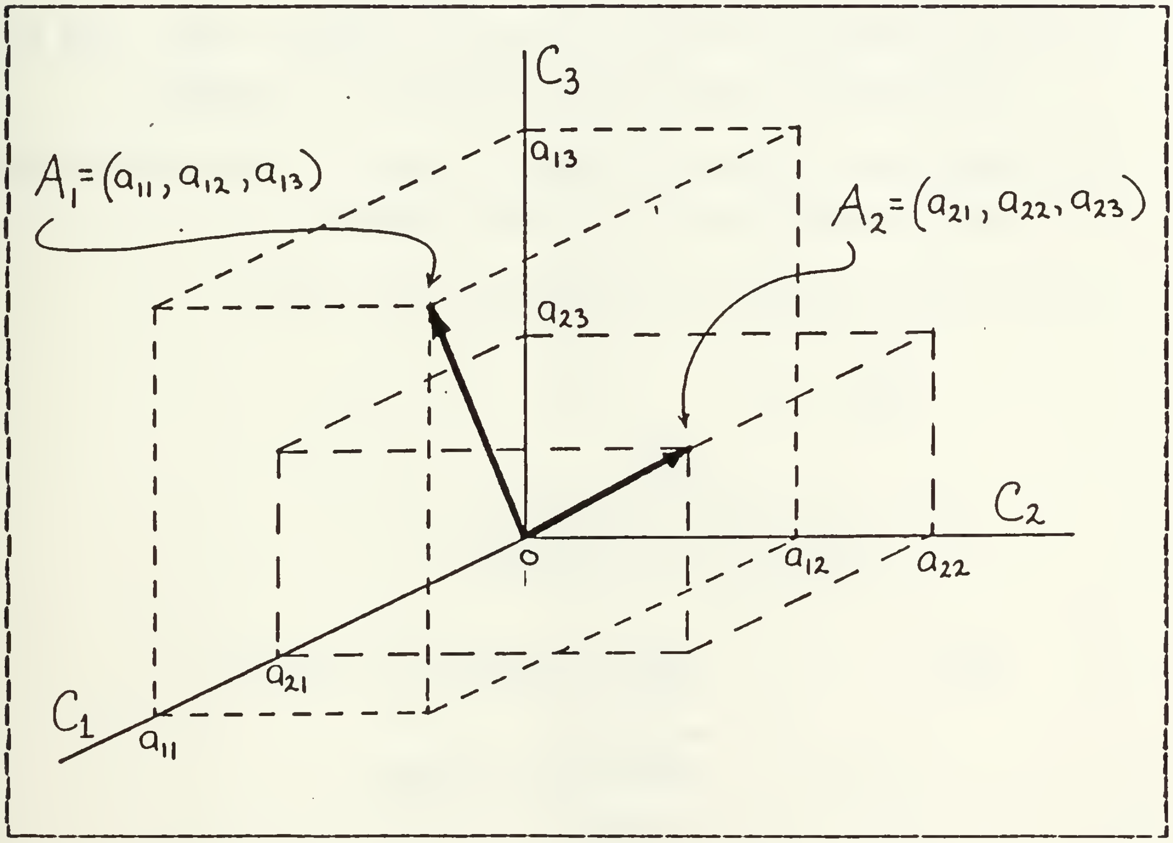


Figure F.3 Vector to Scalar Transformation in 3-Space.

By extension of 2 and 3-space geometric properties into the j-space of Chapter VI, a point more distant from the origin in this j-space is ranked better across all equivalent dimensions or criteria (e.g.: a nearer to optimal mix of rankings).

6. Calculation & Results of the Pair-wise Mann-Whitney Test

The pair-wise Mann-Whitney comparisons were done on both the near term and long term alternative data sets. The results for the near term are shown in Table 18 while results for the long term are in Table 19 below. The Mann-Whitney test is fully explained in Conover [Ref. 26: pp. 216-218]. The process in summary is:

a) The elements of the alternative vectors A(i) and A(j) are combined and ordered smallest to largest.

b) Ranks are assigned to each value. Ties are assigned the average rank of the tied values.

c) A test statistic is calculated as below:

$$T = \sum_{i=1}^{J} R(A_i)$$

$$TS = \frac{T - J\,\frac{N+1}{2}}{\left(\frac{J^2}{N(N-1)}\right) \sum_{i=1}^{N} R_i^2 - \left(\frac{J^2 (N+1)^2}{4(N-1)}\right)}$$

where:	J	number of elements in alternative vectors A_i and A_j
	N	$N = 2 \times J$
	$R(A_i)$	rank of the A_i elements
	R_i	all ranks

In Tables 18 and 19 below, each line represents a Mann-Whitney comparison between two alternatives A(i) and A(j) where the (i) and (j) values are shown in columns 1 and 2. The test statistic is shown in column 3 and represents an indication of the direction of preference (if non-zero) or indifference (if zero). This preference, however weak, or indifference is shown in the fourth column.

TABLE 18

MANN-WHITNEY RESULTS - NEAR TERM

A(i)	A(j)	Statistic	Pref Ind
1	2	.000000	1 = 2
1	3	.000000	1 = 3
1	4	.587945	1 > 4
1	5	-.299572	5 > 1
1	6	.000000	1 = 6
1	7	.000000	1 = 7
1	8	.299572	1 > 8
1	9	.299572	1 > 9
1	10	.299572	1 > 10
1	11	.316228	1 > 11
1	12	.623610	1 > 12
2	3	.000000	2 = 3
2	4	.591608	2 > 4
2	5	.000000	2 = 5
2	6	.595341	2 > 6
2	7	.898717	2 > 7
2	8	.595341	2 > 8
2	9	.595341	2 > 9
2	10	.893011	2 > 10
2	11	.154831	2 > 11
2	12	.316228	2 > 12
3	4	.591608	3 > 4
3	5	.000000	3 = 5
3	6	.595341	3 > 6
3	7	.898717	3 > 7
3	8	.595341	3 > 8
3	9	.595341	3 > 9
3	10	.893011	3 > 10
3	11	.154831	3 > 11
3	12	.316228	3 > 12
4	5	-.606977	5 > 4
4	6	.303488	4 > 6
4	7	.898717	4 > 7
4	8	.303488	4 > 8
4	9	.303488	4 > 9
4	10	.893011	4 > 10
4	11	-.440959	11 > 4
4	12	-.299572	12 > 4
5	6	1.083816	5 > 6
5	7	1.857971	5 > 7
5	8	1.083816	5 > 8
5	9	1.083816	5 > 9
5	10	1.845374	5 > 10
5	11	.297670	5 > 11
5	12	.299572	5 > 12
6	7	.948683	6 > 7
6	8	.154831	6 > 8
6	9	.154831	6 > 9
6	10	1.083816	6 > 10
6	11	.000000	6 = 11
6	12	.000000	6 = 12

Table 18

MANN-WHITNEY RESULTS - NEAR TERM (CONT'D)

A(i)	A(j)	Statistic	Pref Ind
7	8	-.619324	8 > 7
7	9	-.619324	9 > 7
7	10	.316228	7 > 10
7	11	.000000	7 = 11
7	12	.000000	7 = 12
8	9	.000000	8 = 9
8	10	.774154	8 > 10
8	11	-.146986	11 > 8
8	12	.000000	8 = 12
9	10	.774154	9 > 10
9	11	-.146986	11 > 9
9	12	.000000	9 = 12
10	11	-.146986	11 < 10
10	12	.000000	10 = 12
11	12	.316228	11 > 12

TABLE 19

MANN-WHITNEY RESULTS - LONG TERM

A(i)	A(j)	Statistic	Pref Ind
1	2	-.986186	2 > 1
1	3	-.990659	3 > 1
1	4	-1.014072	4 > 1
1	5	-1.725124	5 > 1
1	6	-1.473868	6 > 1
1	7	-1.473868	7 > 1
1	8	-.588348	8 > 1
1	9	-.706877	9 > 1
1	10	-.656252	10 > 1
1	11	-.902866	11 > 1
1	12	-1.350184	12 > 1
2	3	.118246	2 > 3
2	4	.194392	2 > 4
2	5	-.477493	5 > 2
2	6	-.077819	6 > 2
2	7	-.077819	7 > 2
2	8	.848270	2 > 8
2	9	.658581	2 > 9
2	10	.734034	2 > 10
2	11	.159098	2 > 11
2	12	-.512664	12 > 2
3	4	-.117338	4 > 3
3	5	-1.100033	5 > 3
3	6	-.779432	6 > 3
3	7	-.779432	7 > 3
3	8	.590023	3 > 8
3	9	.432683	3 > 9
3	10	.386790	3 > 10
3	11	-.235339	11 > 3
3	12	-1.018835	12 > 3
4	5	-1.013261	5 > 4
4	6	-.626305	6 > 4
4	7	-.626305	7 > 4
4	8	.902500	4 > 8
4	9	.702895	4 > 9
4	10	.581100	4 > 10
4	11	-.311275	11 > 4
4	12	-1.236103	12 > 4
5	6	.469729	5 > 6
5	7	.469729	5 > 7
5	8	1.945472	5 > 8
5	9	1.712015	5 > 9
5	10	1.470380	5 > 10
5	11	.472596	5 > 11
5	12	-.581055	12 > 5
6	7	.000000	6 = 7
6	8	1.730734	6 > 8
6	9	1.483889	6 > 9
6	10	1.170083	6 > 10
6	11	.000000	6 = 11
6	12	-1.116947	12 > 6

Table 19

MANN-WHITNEY RESULTS - LONG TERM (CONT'D)

A(i)	A(j)	Statistic	Pref Ind
7	8	1.730734	7 > 8
7	9	1.483889	7 > 9
7	10	1.170083	7 > 10
7	11	.000000	7 = 11
7	12	-1.116947	12 > 7
8	9	-.118634	9 > 8
8	10	-.351447	10 > 8
8	11	-1.047222	11 > 8
8	12	-1.794847	12 > 8
9	10	-.194161	10 > 9
9	11	-.814506	11 > 9
9	12	-1.537192	12 > 9
10	11	-.772061	11 > 10
10	12	-1.529706	12 > 10
11	12	-.830832	12 > 11

Grouping the results so that the direction of preference is left-to-right (i.e.: LHS > RHS) as in Table 10 and then counting the number of left-hand-side occurances of each alternative, it is possible to rank them. Ties, if any, are broken by examination of the tied alternatives for a preference among themselves. Additionally, it is necessary to examine closely related scores (+/-2) to determine if there are any inferences of overriding preference to be resolved. It is concluded from this summary that: "5" is preferred to "2/3" > "1" > "11" > "4" for the near term. Note that "11" scores lower but was given explicit preference over "4". The long term result is "12" preferred to "5" > "7/6" > "2" > "11". Note that the tie between "6" and "7" was resolved since "7" scores higher in criteria 9 (PIP) and is therefore preferred to "6".

APPENDIX G

SUMMARY OF LFICS RELATED ISSUES FOR FUTURE STUDY

This appendix contains topics concerning issues raised by this study as well as collateral items of impact on telecommunications and LFICS in general. These topics should be examined in future studies and theses.

1. Automation of Technical Control

It is suggested that a study or theses be directed at a much deeper probe of the automation question than was provided in this study. There is a wealth of literature on the subject in the military and industrial communities. The US Air Force, US Army and industry are turning to automation to assist in the management and control of high-speed digital data networks. Since LFICS will eventually transition from a hybrid analog/digital system to an all digital system, we will be faced with the same management and control situation. Looking farther into the future, we see the introduction of packet switching networks which will have more complex inherent management and control difficulties. We must leave the era of "reactive" manual and semi-automatic communications technical control under these circumstances. The following questions are raised for discussion:

a) Is automation really necessary?

b) What is the impact of not having automated monitoring and test procedures in the LFICS technical control facility?

c) Is it possible to have automation and retain manual capability?

d) Does the high-speed digital data environment demand automation?

e) Does the common-user circuit switched digital data LFICS network demand automation?

f) Will a packet switched digital data network demand automation?

2. Nodal Communications-Electronics Readiness Reporting

This issue relates to the formulation of a true "measure of effectiveness" or state of communications-electronics operational readiness in the readiness reporting system. It is suggested that a unit's communications-electronics mission profile could be formulated using the defined LFICS architecture and several typical mission scenarios. The available unit assets would be screened against this profile by category (terminal eq., single-chan radio, circuit switch, etc.) and an aggregated MOE calculated. This MOE would be a more meaningful measure than we utilize today. The technique currently in use fails to consider the categories of equipment and the role this plays in the ability to execute a communications mission within the LFICS architecture.

Background work would include: equipment and LFICS architecture data base preparation, system modeling, simulation, etc.

3. Statistical Monitoring Algorithms

It was mentioned in the discussion of automated monitoring of circuits that the technique could be continuous (meaning "round-robin", each circuit taking its turn) or statistical. The statistical technique would monitor selected circuits more often based on priority, traffic load, error probability, or "fix when failed", etc. Once the technique were developed, it could be implemented in software for an automatic facility or it could be utilized manually or semi-automatically.

This work would require network modeling, traffic analysis, simulation, statistical analysis, development of algorithms, dynamic programming, etc.

4. The AN/TTC-42 ("Super" Enhanced) Combined SW/MPLX/TCF

The explicit direction of the US Marine Corps Command and Control Master Plan is that the AN/TTC-42 will be a highly capable replacement for both the AN/TTC-38 Analog Circuit Switch and the AN/TSQ-84 Technical Control Facility. The indications from conversations with contacts in the development community is that this is not presently the case. It seems that the AN/TTC-42 lacks the capability to perform many of the basic tasks and procedures which are within the capability of the AN/TSQ-84. It lacks the capability to perform: circuit line conditioning; meaningful circuit monitoring, testing, and quantification of results (e.g.: it lacks: S/N test set, oscilloscope, spectrum analyzer, etc.) If, in fact, the AN/TTC-42 is to replace both the TTC-38 and TSQ-84 then action is required to insure that it is enhanced beyond the current planned level. It is suggested that a study look into the apparent shortcomings of the AN/TTC-42 in the area of technical control capabilities and make recommendations on required modifications in consideration of its use as an integrated SW/MPLX/TCF.

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